GRASMOD, A GRASSLAND MANAGEMENT MODEL TO CALCULATE NITROGEN LOSSES FROM GRASSLAND

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Summary

In the framework of the project 'Optimization of roughage production and the use of animal manure in relation to environmental demands' a grassland management model, GRASMOD, was developed to quantify inputs and outputs, both intended and unintended ones, in a consistent way for a wide range of grass production systems. The results will, in addition to other data covering the winter period and other crops, be used for optimization of forage production systems with respect to agronomic, environmental and economic goals. However, the model can also be used independently to examine the effects of grassland management and fertilizer regime on grass and milk production, and on emissions to the environment.

Nitrogen (N) flows in grassland received most attention, as dairy farming is the main source of ammonia volatilization and contributes considerably to nitrate leaching, especially on sandy soils. The potassium (K) flow was also considered, but in less detail than the N flow.

In this report the structure of the model and the underlying relations and assumptions are described for well-drained sandy soils, cultivated continuously with grass and with an adequate water-holding capacity. All results refer to one ha of grassland. This implies that some of the results refer to the summer season, e.g ammonia volatilization, and others to a whole year, e.g. nitrate leaching. The relations and assumptions used in the model were derived from literature, consultation with experts and standards used by the Dutch extension service. Emphasis in the model is on the relation between plant production and N use efficiency.

To run the model, various system characteristics need to be defined: grassland utilization method (zero grazing without supplementation of silage maize, zero grazing with supplementation of silage maize, day-and-night grazing or day-grazing-only with supplementation with silage maize), cutting percentage, fertilizer application rate, milk production per cow per year (5 000, 6 500 or 8 000 kg) and the type of concentrates to be used (standard or low protein concentrates). Each combination of input data characterizes one specific production system.

The results of the model consist of tables containing the following data: the overall results for one ha grassland; the average diet per cow;

N balance sheet for grassland; N balance sheet for the soil, both for organic and inorganic N; N balance sheet for dairy cows; N input/output table; K balance sheet for grassland; K balance sheet for the soil; K balance sheet for dairy cows; K input/output table; details of urine and faeces patches.

Samenvatting

Binnen het projekt 'Optimalisering van ruwvoederproduktie en gebruik van dierlijke mest in relatie tot milieu-eisen' is een graslandbeheersmodel, GRASMOD, ontwikkeld, om op een consistente manier aanvoer en afvoer van stikstof, zowel gewenste als ongewenste, te kunnen kwantificeren voor een breed scala van grasproduktiesystemen. De resultaten worden tesamen met andere gegevens betreffende het winterseizoen en andere gewassen, gebruikt om ruwvoederproduktiesystemen te optimaliseren naar landbouwkundige, milieukundige en economische doelstellingen. Het model kan echter ook onafhankelijk hiervan gebruikt worden om de effecten van graslandgebruik en -bemesting op gras- en melkproduktie en op N-verliezen naar het milieu te kwantificeren.
De nadruk ligt op stikstofstromen in grasland, omdat de melkveehouderij in Nederland de belangrijkste bron is voor ammoniakvervluchtiging en een grote bijdrage levert aan nitraatuitspoeling, met name op zandgronden. Kaliumstromen worden minder gedetailleerd berekend.
In dit rapport worden de structuur van het model en de onderliggende relaties en aannamen beschreven voor goed ontwaterd grasland op zandgrond met een goed vochthoudend vermogen. Alle uitkomsten worden gegeven per ha. Sommige uitkomsten gelden voor het hele jaar, b.v. nitraatverlies, en andere alleen voor het zomerseizoen, b.v. ammoniakvervluchtiging. De relaties gebruikt in het model zijn afkomstig uit literatuur, van deskundigen of gebaseerd op voor de praktijk gangbare normen. De nadruk ligt op de relatie tussen plantaardige produktie en N efficientie van stikstofgebruik.
Om het model te gebruiken moeten verschillende systeemkarakteristieken worden geselecteerd door de gebruiker: de graslandgebruikswijze (zomerstalvoedering met of zonder aanvulling van snijmaïs, onbeperkt omweiden, of beperkt omweiden met aanvulling van snijmaïs), het maaipercentage, de N-gift, de jaarlijkse melkproduktie per koe (5 000, 6 500 of 8 000 kg) en het type krachtvoer (standaard of eiwitarm). Elke combinatie van invoergegevens karakteriseert één specifiek produktiesysteem.
De resultaten van berekeningen met het model worden gepresenteerd in de volgende tabellen: een overzicht voor 1 ha grasland; het gemiddelde rantsoen per koe gedurende de zomer; een stistofbalans voor grasland, een stikstofbalans voor de bodem, uitgesplitst naar organische en anorganische stikstof; een stikstofbalans voor de melkkoeien; een input/output-tabel voor stikstof; een kaliumbalans voor grasland; een kaliumbalans voor de bodem; een kaliumbalans voor de melkkoeien, een input/output-tabel voor kalium and details over mest- en urineplekken.

1 Introduction

In 1988 the reasearch project 'Optimization of roughage production and the use of animal manure in relation to environmental demands' (project nr. 748) was started at CABO. The main aim of the project is to explore the possibilities for the development of dairy farming systems that are acceptable from both the environmental and the economic point of view.
A dairy farming system consists of a plant production and an animal production part. Plant production has to provide the dairy cows throughout the year with sufficient fodder of a satisfactory quality to produce the required amount of milk, and it has to absorb the manure produced by the animals. The production process inevitably leads to the emission of nutrients into the environment, which may cause pollution of soil, water and air. Both, the plant and the animal sub-system have their own specific environmental effects and those are combined in dairy farming. It this study the emphasis is on the plant production part, which has therefore been worked out in more detail than the animal production part.
A grassland management model, GRASMOD, has been developed in the framework of the project to quantify inputs and outputs, both intended and unintended ones, in a consistent way for a wide range of grass production systems. In a next stage of the project these results will, in addition to other data, be used for optimization of forage production systems with respect to agronomic, environmental and economic goals. However, the model can also be used independently to examine the effects of grassland management and fertilizer regime on grass and milk production and on emissions to the environment.
First the nitrogen (N) flow is considered, as dairy farming is the main source of ammonia volatilization and contributes considerably to nitrate leaching, especially on sandy soils (Ministerie VROM, 1989).
The potassium (K) flow is also considered, but in less detail than the N flow.
Legal restrictions on application of animal manure to agricultural land are based on normative values for phosphorus (P). So far, those norms are so lenient that they do not act as constraints in dairy farm management. However, if the final criterion will be that no more P can be introduced into the production system than the amount that leaves in products allowing for some inevitable losses, dairy farmers will also face a manure surplus, if farm management is not adapted. In GRASMOD, P is not yet considered.
In this report the structure of the model and the underlying relations and assumptions are described for permanent grassland on a well-drained sandy soil with an adequate water-holding capacity. In Chapter 2 the framework of the model is discussed. A description of the underlying principles and the required input data, outline the scope of the model. The basic structure is explained on the basis of a schematic representation of the N flows on grassland. In Chapter 3 the experimental results used for quantification of the main model relations are discussed, and in Chapter 4 the calculations on the N flows. Attention is paid to herbage production, the feed ration of the dairy herd, the influence of grazing on herbage production, and emissions to the environment. To ensure consistency of the N-flows in the calculation procedure, an N balance sheet is drawn. In Chapter 5, K flows in dairy farming systems as modelled in GRASMOD are briefly discussed. A literature review, on the information of which the modelling is based, is described in CABO report no 132 (Van de Ven, 1990).

The model can be used for other soil types and hydrological situations by changing a number of parameters and/or input data.

2 Framework of the model

2.1 Basic considerations

Before GRASMOD was developed, a number of basic principles were defined to set the scope and the boundaries of the model.

(1) The grass production systems whose inputs and outputs are quantified in GRASMOD, were defined in terms of land use. They are characterized by grassland utilization method and fertilizer application rate. Thus, GRASMOD must provide the possibility to calculate inputs and outputs for various combinations of the values of these characteristics.
(2) All calculations refer to one ha on an annual basis. For the purposes of the project, this is acceptable, because it suffices to quantify the relations between N fertilization, herbage production and N emissions for an average situation in an average year. GRASMOD is a static model based on empirical relations.
(3) The relations and assumptions used in GRASMOD were derived from literature, consultation with experts and standards used by the Dutch extension service. If insufficient data were available, the most intelligent estimates for a parameter or set of parameters were used.
(4) GRASMOD only applies to land which is continuously cultivated with grass.
(5) The grassland is situated on a well-drained sandy soil with a favourable soil structure and a good water availability. So far, the influence of water availability on herbage production has not been considered explicitly.
(6) It is assumed that all necessary and normal operations in good grassland management are executed properly. These operations and the required labour and capital inputs are not considered in GRASMOD, but will be taken into account in the linear programming (LP) model.
(7) The results apply to the growing season only. Thus, for a year-round balance additional calculations have to be done.
(8) The model provides a framework for quantification of N flows on grassland in dairy farming systems. It is possible to adapt the model relatively easily to other situations, such as other soil types or beef production.

2.2 User-defined input data

To run the model, various system characterics need to be defined: grassland utilization method, cutting percentage, fertilizer application level, milk production per cow per year and the type of concentrates to be used. Each combination of input data characterizes one specific production system.

2.2.1 Grassland utilization method

Three grassland utilization methods are distinguished: zero grazing, daytime grazing only, from now on referred to as daytime grazing, and day-and-night grazing. The stage at which the herbage is harvested depends on the utilization method and is based on current practices.
Under zero grazing the herbage is cut, when 2 300 kg of harvestable dry matter ha^{-1} is present, and is fed fresh to the dairy cows indoors.
Daytime grazing and day-and-night grazing are both rotational grazing systems, but in the former the cows are outside only during the day and indoors during the night and in the latter the cows are outside througout the whole grazing season. Under daytime grazing the cows are supplemented with silage maize during the night. The difference between the two grazing systems mainly affects grazing and feeding losses and the amount of N directly excreted onto the pasture via faeces and urine and thus N emissions.
In both systems, the cows are shifted every three to five days to another field, with an amount of harvestable dry matter 1 700 kg ha^{-1}. In the model the standard grazing period for a pasture is four days, but that can easily be modified by adapting the grazing losses.

2.2.2 Cutting percentage

All three utilization methods can be combined with cutting herbage for conservation, carried out at a harvestable dry matter yield of 3 000 kg ha^{-1}. The grass silage is fed during winter. However, this is not considered in GRASMOD, but in the LP-procedure.
The cutting percentage indicates the percentage of the area that is cut, hence, it may well exceed 100%, as an area can be cut more than once a year. A cutting percentage of 100% implies that during the growing season one ha ha^{-1} is cut and that herbage yield for conservation is 3 000 kg ha^{-1} yr^{-1}. A cutting percentage of 150% means that 1.5 ha ha^{-1} is cut and the amount of herbage conserved is 4 500 kg ha^{-1} yr^{-1}. In the model the cutting percentage may vary between 0, and cutting all herbage produced, which at the highest production level is almost 500%.

2.2.3 Nitrogen application

Nitrogen can be supplied to the crop in organic and in inorganic fertilizers. In GRASMOD only inorganic fertilizers are considered. The N application rate can vary from 0 to any value, but above about 600 kg N ha^{-1} yr^{-1} uptake will hardly increase in the situation described here. Substitution of inorganic by organic fertilizers will be considered in the optimization procedure.

2.2.4 Milk production

Average production in the Netherlands was about 7 000 kg fat and protein corrected milk per cow in 1990 (LEI & CBS, 1991). To evaluate the influence of milk production per cow on N efficiency, three production levels were defined:
5 000 kg milk cow^{-1} yr^{-1}, representing a low production level;
6 500 kg milk cow^{-1} yr^{-1}, approaching the present production level;
8 000 kg milk cow^{-1} yr^{-1}, representing a high production level.

2.2.5 Type of concentrates

Two choices can be made with respect to concentrate supply: a standard concentrate or an adjusted concentrate mixture. The concentrate has to fulfill energy and protein requirements of the animals. As herbage is the main feed component in most systems, the protein content of the concentrates does not have to be high. When the 'standard' option is chosen first a concentrate with a low protein content is selected and if necessary with respect to protein requirements this is replaced by a standard concentrate. If the 'adjusted mixture' is selected, the protein is adjusted as much as possible to the requirements. The main difference between those options is the N content of the concentrates and the N utilization by the animal. N intake at the standard option is higher, but the costs are lower than at the adjusted mixture option.

2.3 Structure of the model

The structure of the model is based on the nitrogen flows through the dairy farming system, as visualized schematically in Figure 1. The numbers in brackets in the text refer to the numbers in Figure 1.
Inorganic N in the soil originates from decomposition of soil organic matter (1), atmospheric deposition (2) and fertilizers (3). Nitrogen is taken up by herbage (4) from the inorganic N pool. It is assumed that on an annual basis the amount of N taken upt by non-harvestable plant parts (roots and stubble) equals the amount released from them due to senescence and dying down. In the model the base uptake of N, i.e. uptake in the absence of fertilizer application and thus originating from mineralisation and deposition, is assumed constant. If the N uptake required to attain a certain herbage production level, is higher than the base uptake, that part is supplied by N fertilizers. The herbage is consumed by dairy cows and part of the production, including its N, is lost as grazing or harvesting losses in the field (5). Part of the N in grazing and harvesting losses volatilizes as ammonia (6) and part contributes to the soil organic matter (7).
The stocking rate is calculated by tuning net herbage production and energy requirements of the cows, taking into account maximum dry matter uptake from forage, as derived from the feeding norms for dairy cattle. The ration consists of grass (8), supplemented with silage maize and/or concentrates (9), if necessary.

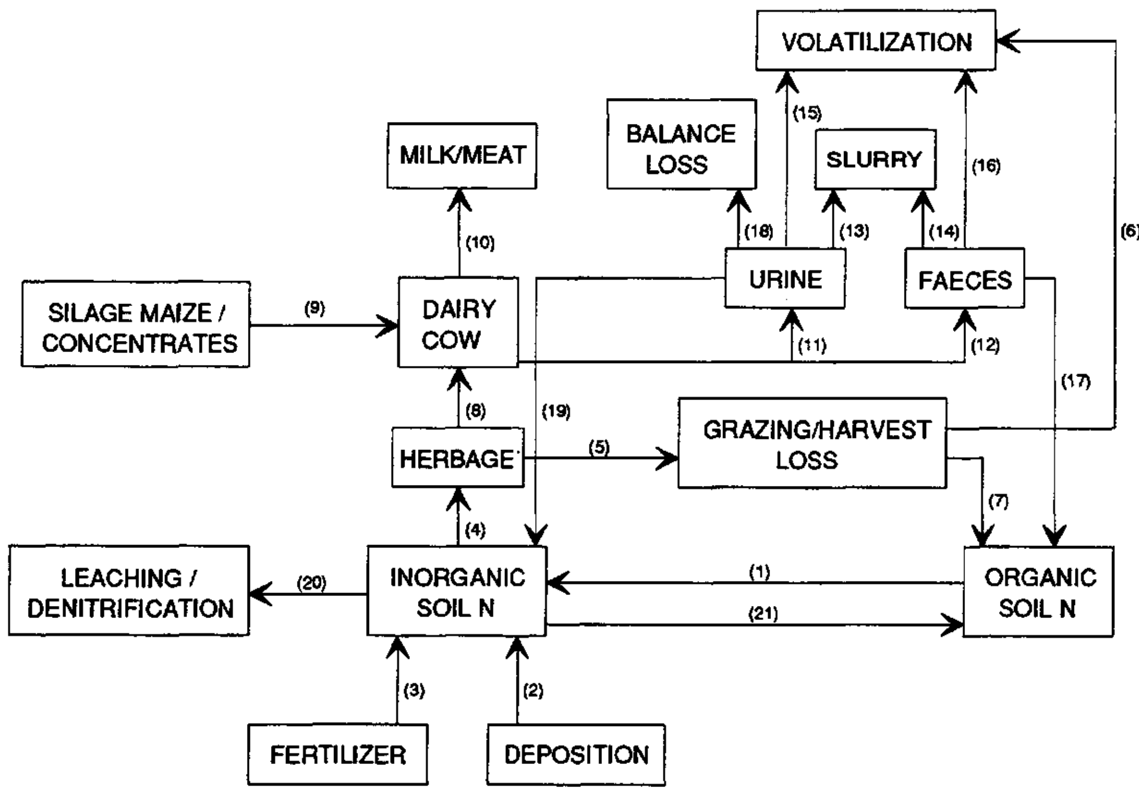

Figure 1. **Schematic presentation of N flows through grassland in dairy farming systems.**

Part of the N taken up by the animals leaves the system in milk and meat (10) and the remainder is excreted in urine (11) and faeces (12). Under all three grassland utilization methods at least part of the N excreted is collected as slurry during milking in the stable (13, 14). During grazing urine and faeces are distributed hetereo-geneously over the pasture and only part of the area, depending on grazing system and stocking rate, is covered.

Part of the N in urine and faeces volatilizes as ammonia (15, 16). The remainder of the N in faeces is considered organic N and contributes to soil organic matter (17). The remainder of the urine N is partly lost through an unknown process, probably chemo-denitrification (18) and partly contributes to the soil inorganic N pool (19).

Inorganic N in the soil is subject to leaching and denitrification (20). It is assumed that all inorganic N, that is not taken up by the herbage, nor denitrified or leached, is immobilized (21). In an equilibrium situation, replenishment of soil organic N by immobilisation, harvest losses and faeces, equals the amount of N supplied to the inorganic pool by decomposition (1). If this replenishment exceeds mineralisation, assuming that no other losses occur than described in this section, N will accumulate in the soil organic matter. If replenishment is not sufficient to compensate for mineralisation, soil organic N will be depleted.

The K flows through the dairy farming system are calculated in basically the same way as the N flows. In Figure 1, just two modifications were necessary:

- K is only lost to the environment by leaching;
- K is mainly present in the soil in inorganic form; a balance between K in the soil solution, K adsorbed to soil particles and K bound in minerals and organic matter is continuously being established.

3 Quantification of main model relations

Emphasis in the model is on the relation between plant production and N use efficiency. The main model relations concerning this aspect were quantified by analysing results from field experiments, as is described in this chapter.

3.1 Theoretical and experimental basis of the main model relations

Herbage production is determined by growing conditions and water and nutrient supply (Noij, 1989; Van Keulen & Wolf, 1987). The growing conditions concern
- the length of the growing season; under Dutch climatic conditions the onset of growth in spring is mainly governed by temperature and the end of it in autumn by light intensity;
- the amount of radiation intercepted by the crop; this depends on the amount of incoming radiation and the fraction of it that is intercepted by the crop. This fraction is governed by harvesting frequency, sod quality and rate of regrowth after cutting.

The water supply mainly influences herbage production via opening of the stomata and leaf elongation during regrowth.
The nutrient supply influences the growth rate and the quality of the herbage.
In GRASMOD herbage production is quantified for a well drained sandy soil under average weather conditions, so growing conditions that cannot be influenced by management and nutrient supply were standardized. It was assumed that all necessary and normal operations in good grassland management were executed properly. Therefore, sod quality was considered to be good.
This leaves harvesting frequency and nutrient supply as the main production determining variables. After harvesting, pasture growth rate is reduced during a certain period of time due to defoliation. The drastic reduction in leaf area results in a reduced light interception and thus in reduced photosynthesis. It takes some time before the growth rate has been restored. The cutting frequency determines the number of periods with reduced growth and hence the total annual length of that period. Therefore, total annual dry matter production decreases with increasing harvesting frequency (Sibma & Ennik, 1988; Prins, 1983; Sibma & Alberda, 1980; Holliday & Wilman, 1965).
In GRASMOD, N is considered the main production limiting factor. As for the other macro nutrients, the potassium cycle is only quantified in relation to the N cycle and the phosphorus cycle has not been quantified so far.
The respons of herbage production to N application is often analysed in three steps in a 'three quandrants figure', as introduced by De Wit (1953; Figure 2).

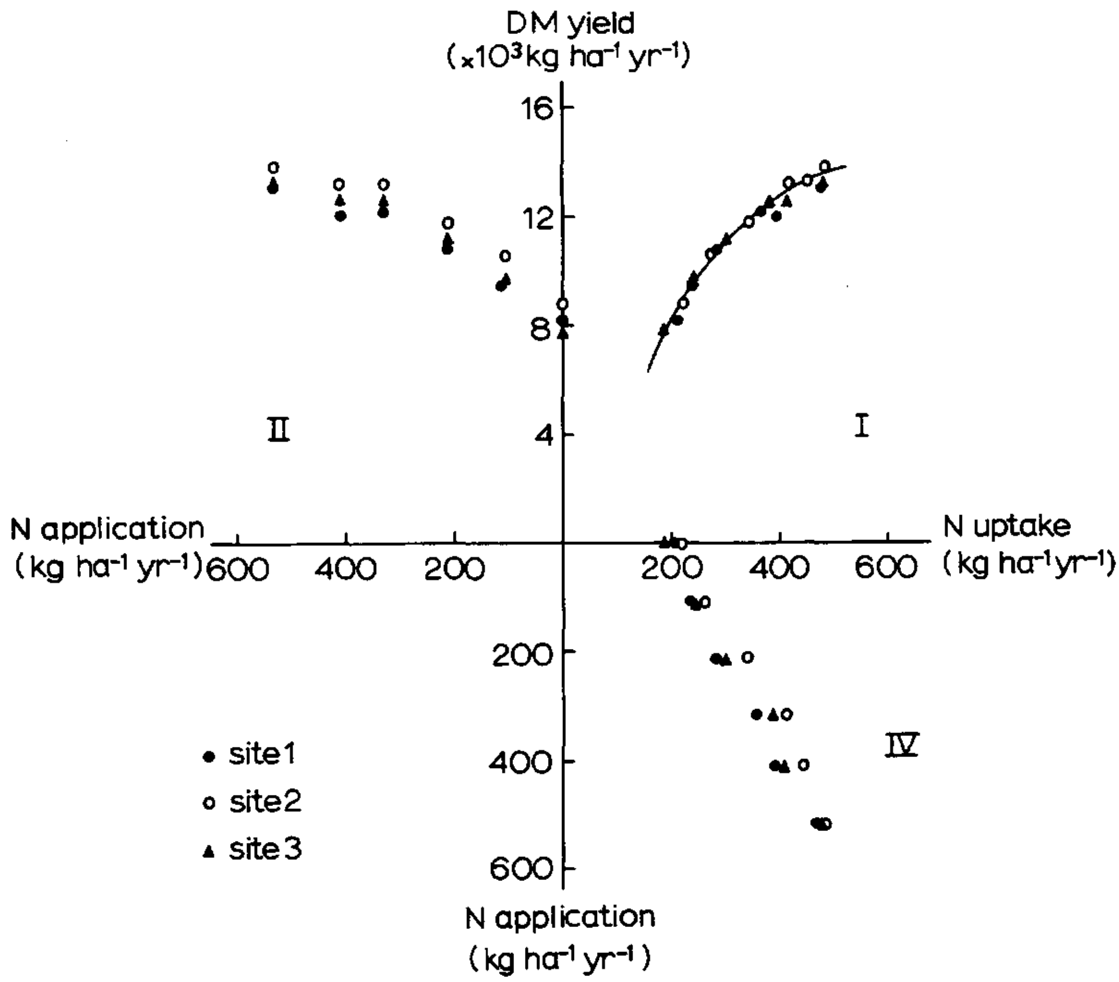

Figure 2. Response of herbage production to N uptake (I), to N application (II) and the apparent N recovery (IV) for the field experiment PAW 970 (Van Steenbergen, 1977).

Quadrant IV shows the relation between N application and N uptake in the herbage, quadrant II between N application and herbage production and quadrant I between N uptake and dry matter production. In quadrant I the N cycle of grass is linked to the carbon cycle. The more favourable the growth conditions and the water supply are, the higher the herbage production is at a particular N uptake. This effect increases with increasing N uptake. Annual N uptake by herbage is mainly governed by N application level and far less by cutting frequency (Sibma & Ennik, 1988; Prins, 1983; Sibma & Alberda, 1980; Wieringa, 1978; Alberda, 1973; Cowling, 1966; Holliday & Wilman, 1965). Based on this information, N uptake in GRASMOD is assumed to be determined by N application level only, irrespective of cutting frequency.

For GRASMOD, the relation between N uptake and herbage production is required for the three harvesting frequencies indicated in sections 2.2.1 and 2.2.2: harvesting at 1 700, 2 300 and 3 000 kg of consumable dry-matter per ha. However, in most field experiments a constant cutting-interval is used. In such experiments, the weight of the consecutive cuts decreases, because herbage growth rate decreases in the course of the growing season. Van

Steenbergen carried out an extensive series of field experiments (PAW 970) aimed at cutting at predetermined herbage yields. The experiments were established on 24 permanent grassland sites, representing eight major combinations of soil type and soil moisture regime, and lasted 10 years (1964-1973). N application rates ranged from 0 to 500 kg ha^{-1} yr^{-1}. The results of PAW 970 were re-analysed in such a way that it was possible to derive a relation between N uptake and herbage yield for the three harvesting frequencies mentioned earlier. For reasons explained in Section 3.3 the relation between N application rate and N uptake is based on other experiments.

3.2 Nitrogen uptake and herbage production

3.2.1 The lay-out of PAW 970

The experimental fields in PAW 970 were situated on permanent grassland on commercial farms. Each combination of soil type and soil moisture regime was situated on three different locations and these were considered replicates. The botanical composition indicated a good soil fertility status and good grassland management. Each replicate consisted of six plots with different N application rates: 0, 100, 200, 300, 400 and 500 kg ha^{-1} yr^{-1}. As continual cutting, as was the case in PAW 970, might influence sod quality, the field was divided into five parts and the experiment rotated on those parts. Thus, each year one of the five parts was harvested. The four other parts were fertilized similarly to the harvested one, but they were used by the farmer together with the surrounding fields. The farmer was free to cut the grass or have it grazed and to apply slurry or farm yard manure.
The first cut was a hay cut of about 4 000 kg ha^{-1}, the second and the third cut were pasture cuts (1 500-2 000 kg ha^{-1}), the fourth cut was a pasture cut at the N application rates below 300 kg ha^{-1} yr^{-1} and a silage cut (2 500-3 000 kg ha^{-1}) at higher N application rates. The following cuts were again pasture cuts (De Boer, 1966). As at low N rates the total herbage production was lower than that at the high N rates, the number of cuts finally realised varied for the various N application rates. For a more detailed description of the lay-out of PAW 970 reference is made to Van der Meer (1982), Van Steenbergen (1977), Jagtenberg & De Boer (1967) and De Boer (1966).

3.2.2 Water availability

For this study only the results on sandy soils are considered. In the experimental set-up the sandy soils were combined with three soil moisture classes: well-drained ('normal'), poorly drained ('wet') and drought-susceptible ('dry'). The amount of water available in the rooting zone during the growing season in addition to rainfall is given in Table 1 (Van Soesbergen, unpublished data).

Table 1. The average amount of available water in the rooting zone, in addition to rainfall for three hydrology classes on sandy soils, in mm yr^{-1}.

hydrology class	water holding capacity	capillary rise	total soil water supply
dry	90	30	120
normal	130	30	160
wet	110	>90	>200

Source: Van Soesbergen, unpublished data

Part of the available water originates from capillary rise, which implies an influence of the groundwater table. Over the past decades the average depth of the groundwater table in sandy areas in the Netherlands has increased, but possibilities for irrigation also have increased. Thus, despite the lower water table at present, the sandy soils with a 'normal' water availability were considered to represent the average situation and the results belonging to that combination were analysed for use in GRASMOD.
At this stage, the influence of water availability as such is no object of study. GRASMOD applies to sandy soils with a water availability of about 160 (150-175) mm yr^{-1}. The origin of this water, whether it is from capillary rise, water holding capacity of the soil or irrigation, is not considered.
In conclusion, for GRASMOD the results from the three locations on a sandy soil with a 'normal' water availability (locations no's 16, 17 and 18 out of the total of 24) were re-analysed to arrive at a standardized relation between N uptake and herbage production for three cutting frequencies.

3.2.3 Nitrogen uptake and herbage production as derived from PAW 970

During the first few days after cutting regrowth results from elongation of the herbage left in the stubble after harvesting. As soon as photosynthesis is well under way, dry matter increases exponentially until full ground cover is reached. Then it passes into a linear growth phase and finally, the growth rate slowly decreases. However, herbage is usually harvested before this last phase is reached (Alberda & Sibma, 1968). The slope of the curve is influenced by light intensity, temperature, moisture, grass species and variety and N availability and the initial biomass after cutting.
In Figure 3, the dry matter production and the number of growing days are given for an arbitrary cut in PAW 970 (point A). The solid line represents the growth rate in the course of time, assuming exponential growth initially, followed by linear growth after full ground cover is reached. The dotted line shows that assuming a constant growth rate would underestimate the period required for a herbage yield lower than A and overestimate the period required for a higher yield.

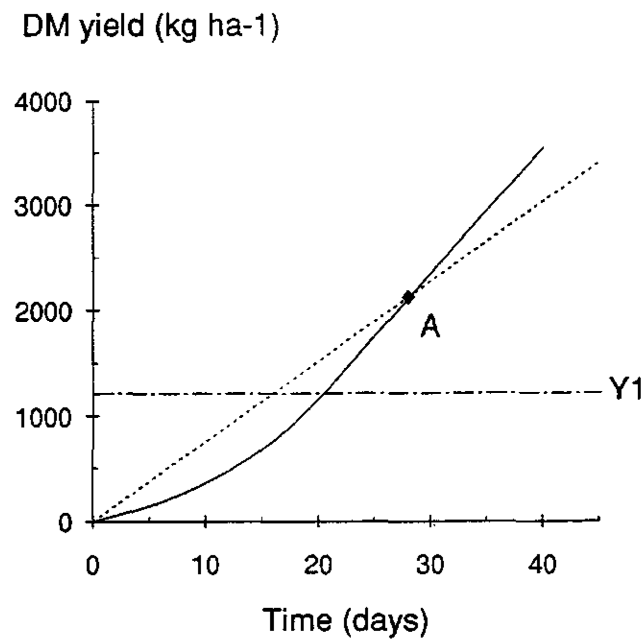

Figure 3. Growth curves of grass after cutting for exponential (___) and linear (....) growth rates. Y1: yield at which full ground cover is reached; A: data from PAW 970.

For the analysis of the results of PAW 970 the following relations were used:

$Y_t = Y_0 * e^{RGR*t} - Y_0$	for Y_t _ Y_1	(kg ha^{-1})
$Y_1 = Y_0 * e^{RGR*t1} - Y_0$		(kg ha^{-1})
$Y_t = LGR * (t-t_1) + Y_1$	for $Y_t > Y_1$	(kg ha^{-1})

Y_t : herbage grown in t days
t : number of growth days (d)
Y_0 : initial biomass that contributes to photosynthesis (kg ha^{-1})
Y_1 : herbage yield at which full ground cover is reached (kg ha^{-1})
t_1 : number of days required to reach full ground cover (d)
RGR : relative growth rate (kg kg^{-1})
LGR : linear growth rate (kg d^{-1})

Of each cut, Y_t and t were known. Values for Y0 and Y1 were based on literature (Spitters et al., 1989; Sibma & Ennik, 1988; Lantinga, 1985; Alberda, 1973; Alberda & Sibma, 1968) and estimated at 300 and 1 200 kg ha^{-1}, respectively. It was assumed that after cutting, a stubble of 3 000 kg dry matter remained, of which 10 per cent consisted of leaves (Y_0). Newly-grown herbage consists mainly of leaves (Y_1), so total leaf biomass at full ground cover, which is generally reached at a leaf area index of about 4, was 1 500 kg. This implies the specific leaf weigth was about 270 cm2 g^{-1}, which is a reasonable value for grass (Lantinga, 1985).
On the assumption that at Y_1 the growth rate does not change abruptly (Figure 3), the moment of full ground cover and the relative and the linear growth rates were calculated.
In Figure 4 the average growth rates during the linear phase of regrowth (kg d^{-1}) over ten years and the standard deviations are given for all cuts and N application rates as calculated for location 16. The results for location 17 and 18 are similar. As the treatments were identical

during all years, the variation in growth rates, as given in Figure 4, is determined by differences in weather conditions during the ten years of the experiment.

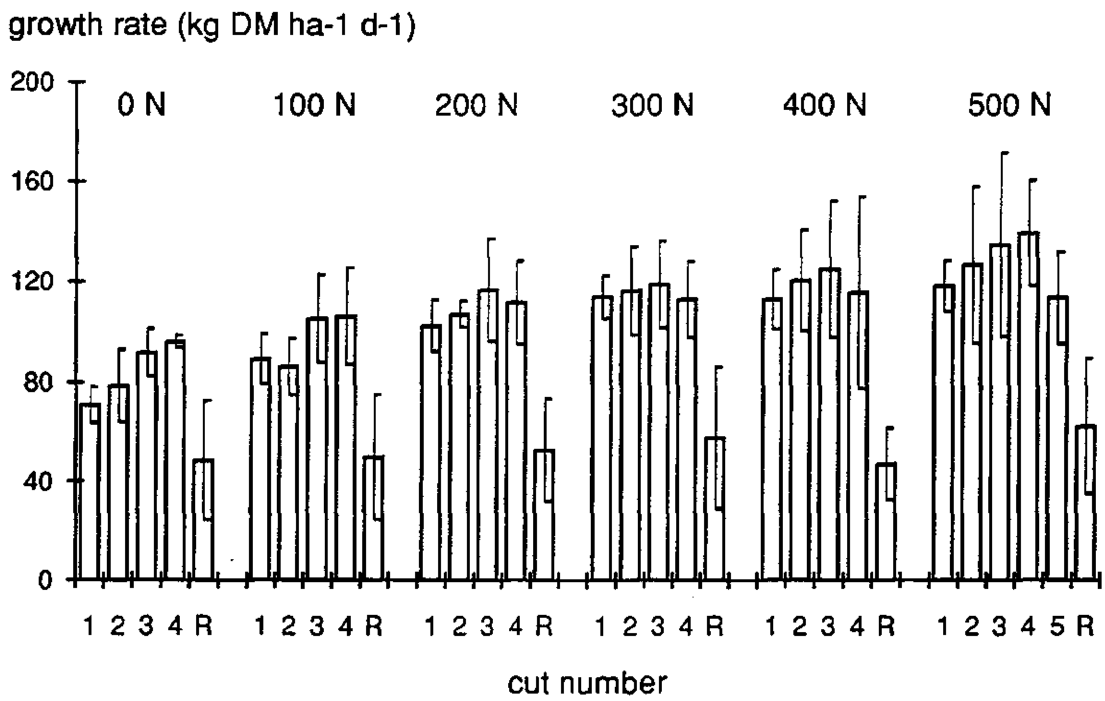

Figure 4. **Average growth rates in the linear phase of regrowth and the standard deviation ($kg\ ha^{-1}\ d^{-1}$), for all cuts and N application rates at location 16.**

In late summer and autumn, growth rates decrease due to decreasing light intensities and temperatures. Therefore, the cuts of which the herbage had grown for the largest part after 15 August were lumped (R in Figure 4). Water availability in this period depends on rainfall and on the weather conditions during the summer period. After a dry summer all available water has been used and drought stress may occur. Thus, fluctuating weather conditions explain the large variation in the growth rate during the last period.

The onset of growth was set at a fixed date, 1 April, in all years. Variation in the calculated growth rates was expected to be rather high, because, in addition to soil type and drainage situation, weather conditions in spring influence the actual onset of growth. At location 16 this influence was small (Figure 4).

Figure 4 shows that at low N application rates the standard deviation is smaller than at high rates. This indicates that at a higher N availability, growth becomes more dependent on moisture supply.

Figure 4 also shows that during summer, average growth rates at a given N rate did not differ much and therefore, the growing season was divided into three periods:

- 1 April to the harvest of the first cut
- from the harvest of the first cut to 15 August
- 15 August to 1 November.

For all three periods the number of days to reach a closed canopy and the linear growth rates were averaged (Table 2).

Table 2. The average number of days after cutting required to reach a closed canopy for three periods (T1 in days) and the growth rate during the linear phase of regrowth (LGR in kg d^{-1}) for 6 N application rates.

	cut	N application (kg ha^{-1} yr^{-1})					
	number	0 N	100 N	200 N	300 N	400 N	500 N
T1	cut 1	33	26	23	21	21	21
	cut 2-5	29	25	22	21	20	19
	R	72	70	62	65	58	59
LGR	cut 1	75	94	107	116	117	120
	cut 2-5	87	99	113	120	126	131
	R	41	47	53	56	51	57

Subsequently, the number of days required for the production of 1 700, 2 300 and 3 000 kg ha^{-1} were calculated, and finally the annual herbage yield was derived from the number of cuts that could be harvested.
For reasons explained in Section 3.3, N uptake instead of N application rate was taken as the independent variable. Hence, the herbage yield was related to average annual N uptake. As it was assumed that harvesting frequency does not influence N uptake by herbage (Section 3.1), the average N uptake at each fertilizer level, as measured in PAW 970, applies to all three cutting frequencies. The relation obtained in this way is presented in Figure 5. The symbols represent the calculated herbage yield at the average measured N uptake and the lines are fitted by eye.

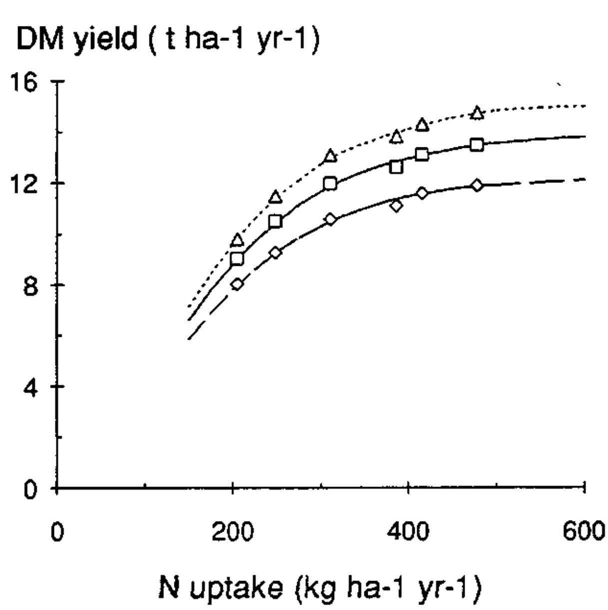

Figure 5. The relation between N uptake and gross dry matter production at three harvesting frequencies: harvesting at 1 700 (----), 2 300 (___) and 3 000 (....) kg per ha.

Using these relations, the model was run for the combination of grassland utilization methods applied in PAW 970 (Section 3.2.1), to check the calculations. In Table 3 the results from GRASMOD are compared to the experimental data of PAW 970 (Van Steenbergen, 1977). It shows that the calculations have been executed correctly. The small deviations are due to the differences between calculated and measured weights of individual cuts. In field experiments a constant yield of all cuts during the growing season can hardly be realized.

Table 3. Herbage yield measured in PAW 970 and calculated with GRASMOD in kg $ha^{-1}yr^{-1}$ and relative to the measured yields in per cent.

N application	herbage yield (kg $ha^{-1}yr^{-1}$)		relative yield
(kg ha^{-1} yr^{-1})	measured	calculated	(%)
0	8330	8572	103
100	10200	9849	97
200	11280	11153	99
300	12700	12276	97
400	12630	12720	101
500	13390	13046	97

3.3 Nitrogen supply and nitrogen uptake

In non-fertilized grassland, inorganic N in the soil originates from decomposition of organic matter and atmospheric deposition. On sandy soils in the Netherlands N uptake by grass in such situations generally varies between 100 and 250 kg ha^{-1} yr^{-1}, depending on soil conditions, age of the sward and the preceding grassland management, with an average of 150 kg ha^{-1} yr^{-1} (Van der Meer 1987; Van der Meer & Van Uum-van Lohuyzen, 1986).
Figure 2-IV shows the relation between N application rate and N uptake in PAW 970. Average N uptake in the non-fertilized situation was 204 kg ha^{-1} yr^{-1} (Van Steenbergen, 1977). The N apparent recovery, defined as the increase in N uptake, expressed as a percentage of the N applied in fertilizer, was rather low, i.e. 40-50%, especially at low fertilizer levels.
The low recovery at low fertilizer rates may be due to the presence of clover in the swards, which at low fertilizer levels may have contributed considerably to the total N yield. The influence of clover on N recovery is illustrated in Figure 6 by results obtained by Reid (1970). In the non-fertilized situation N uptake by the grass/clover sward was 230 kg ha^{-1} yr^{-1}, while it was only 45 kg in the pure grass sward. In the grass/clover sward, the apparent N recovery at low fertilizer rates is low compared to that observed on the pure grass sward. At N fertilizer rates above 250 kg ha^{-1} yr^{-1} the N recovery on the two sward types hardly differs anymore. Reid (1970) reported that the mean clover content, as percentage in the total dry matter yield, decreased from 40% at 0 N to less than 5% at 250 N ha^{-1} yr^{-1}. At increasing fertilizer rates, the competitive ability of grass increases and clover content and thus N fixation decrease. Hence, N fixed by clover is gradually substituted by fertilizer N (Van der Meer, 1982). Although less extreme than in the experiments of Reid (1970), the presence of clover partly caused the low N recovery obtained in PAW 970.
Another reason for the rather low recovery at all fertilizer rates might be the application of manure and of faeces and urine by grazing animals during the four years a plot was not harvested in the experiment (Section 3.2.1). It is unknown how much manure was applied during the experimental period, but on all three sites the farmers used to apply animal manure once a year in the years preceeding the experiment (Jagtenberg & De Boer, 1967).

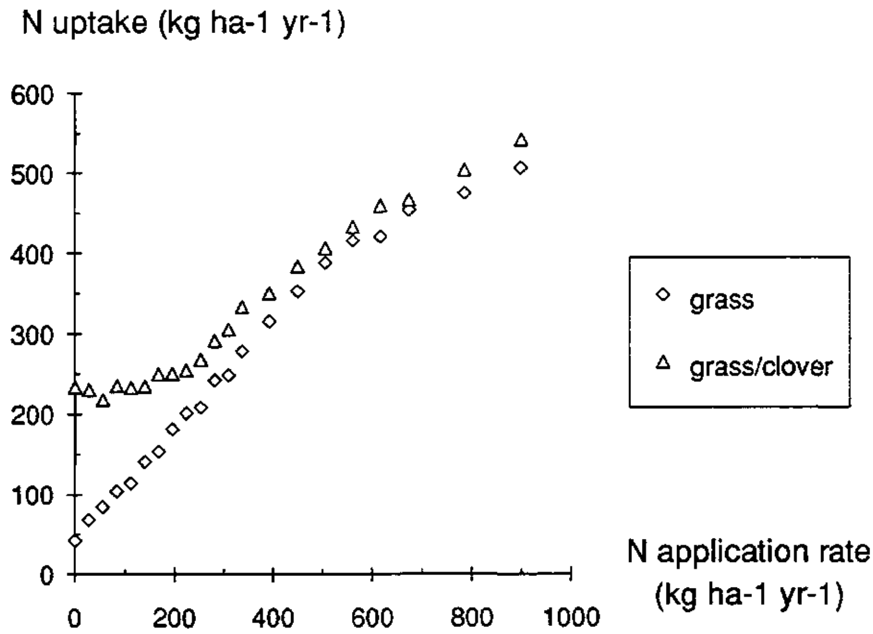

Figure 6. The relation between N application rate and N uptake by grass/clover and by pure grass swards (source: Reid, 1970).

Furthermore, an extensive analysis of the results from N fertilizer experiments on grassland in the Netherlands indicated that the N recovery had increased between 1970 and 1985 from about 50 to 80% (Van der Meer & Van Uum-van Lohuyzen, 1986). Thus, the relation between N application and N uptake as established in PAW 970 seems to be unsuitable for characterization of present grass production systems. Therefore, the results of other experiments were used to quantify that relation.

Prins (1983) reported the results of a fertilizer experiment on grassland on a sandy soil in Finsterwolde. Snijders et al. (1987) reported the results of three fertilizer experiments on grassland on sandy soils. In one of those experiments, dry matter production exceeded 15 ton ha^{-1}, indicating that the production potential of the sward on that soil was higher than that on the sandy soil in PAW 970. Therefore, this experiment was not considered. Figure 7 shows the relation between N uptake and dry matter production and that between N application by inorganic fertilizers and N uptake by herbage of the three remaining experiments.

The upper quadrant (I) shows that the maximum production level in the three experiments approached that attained in PAW 970. The lower quadrant (IV) shows that N uptake in the non-fertilized situation varied between the various experiments and influenced the position of the lines. To exclude this influence N uptake was expressed in relation to the total N supply, both by the soil and by fertilizers. For that purpose, it was assumed that the recovery of N supplied by the soil equals that of the lowest N rate in each experiment, as this relation seems linear at low N application rates, and available soil N, thus calculated, was added to the fertilizer rate (Figure 8).

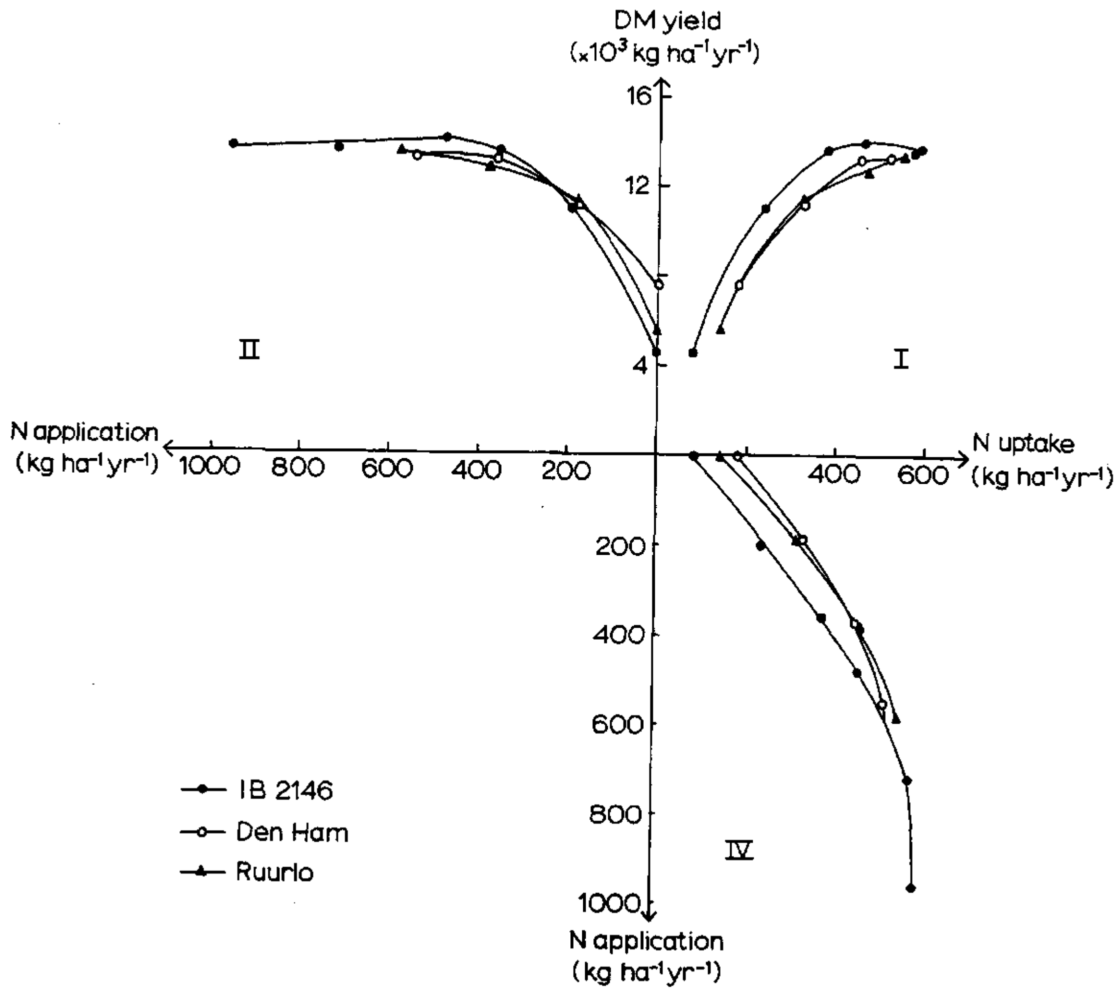

Figure 7. **Response of herbage production to N uptake (I), to N application (II) and the apparent N recovery (IV) for experiments in Den Ham (1979-1983), Ruurlo (1980-1984), Finsterwolde (1974-1979).**

The average initial slope of the curve is 0.85, indicating that of each kg N applied 0.85 kg was taken up by herbage. Assuming the amount of N taken up without fertilizer application was 150 kg ha^{-1} yr^{-1} (Van der Meer, 1987), the amount of N available in the soil without fertilizer application was 176 kg ha^{-1} yr^{-1}. As mentioned earlier, this amount originates from atmospheric deposition and decomposition of organic matter. It is assumed that deposition occurs evenly distributed over the whole year and is on average 45 kg N ha^{-1}. N deposited in late autumn and winter is subject to loss processes. It was estimated that 70% of the annual deposition is available for plant uptake (Van der Meer, pers. comm., Middelkoop & Aarts, 1991), which in this case is 31 kg ha^{-1} yr^{-1}, implying that 145 kg N ha^{-1} yr^{-1} originates from decomposition of organic matter.
Grass is a perennial crop with a long growing season compared to annual crops. However, part of the decomposition of organic matter occurs beyond the growing season, as the minimum temperatures required for herbage growth are somewhat higher than those required for decomposition.

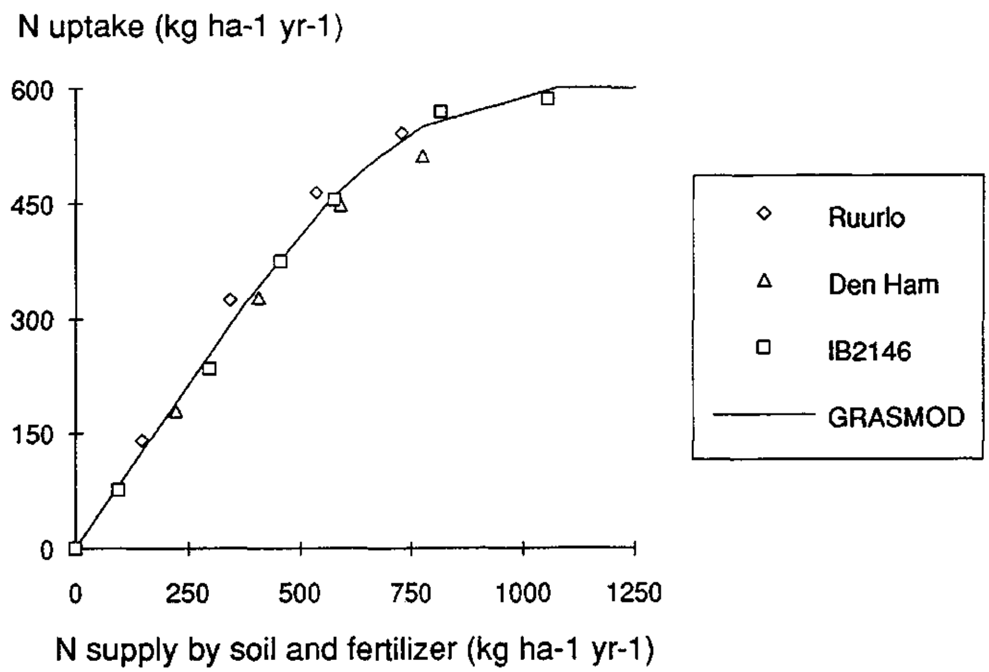

Figure 8. The relation between the amount of N supplied by the soil and by fertilizers and N uptake for Den Ham (1979-1983), Ruurlo (1980-1984) and Finsterwolde (1974-1979) and as derived for GRASMOD.

In early spring the N available through decomposition is probably not lost, but can be taken up by the herbage as soon as growth starts. However, N becoming available in late autumn (November), is subject to loss processes during the following winter period. As a clear influence of season on decomposition of organic matter exists and the mineralization rate is relatively low in late autumn (Jansen, 1986), it is estimated that on average 95% of the N annually becoming available through decomposition, is available for uptake by herbage. This implies a total annual mineralization of 153 kg ha^{-1}.
Table 4 summarizes the assumptions with respect to soil N.

Table 4. Summary of assumptions with respect to soil N for the non-fertilized situation.

characteristic	atmospheric deposition	decomposition soil organic matter	total
Total inorganic N soil (kg ha^{-1} yr^{-1})	45	153	198
fraction available for uptake	0.70	0.95	
N supply to vegetation (kg ha^{-1} yr^{-1})	31	145	176
N recovery			0.85
N yield in herbage (kg ha^{-1} yr^{-1})			150

3.4 Nitrogen supply and potassium uptake

In addition to N, K flows in grassland are also considered in GRASMOD. Based on a literature review (Van de Ven, 1990), K uptake by herbage is directly related to the N uptake. However, this literature review was not exhaustive and the description of the K cycle in grassland in this report is a preliminary one.
K is mainly present in the inorganic solid phase of the soil, fixed in minerals, mainly clay minerals and organic matter. At the surface of the negatively charged clay minerals, positive cations can be adsorbed. The adsorption capacity of a soil is determined by the amount and the type of clay minerals and organic matter. Plants take up K from the soil solution, which is replenished by exchange of adsorbed K and, if plant uptake is high, by release of K from the clay minerals.
A balance between K in the soil solution, K adsorbed (exchangeable K) and K fixed in minerals is continuously being established. If no K is applied to a growing crop, the soil is being depleted of K. Exchangeable K is depleted in several years, and thereafter K is supplied by non-exchangeable sources at a more or less constant rate (Clement & Hopper, 1968). The more K is present in the soil, the longer this process can continue. Sandy soils are relatively low in K, owing to their low clay and organic matter content.
The K content in grass varies from 0.5 to 5.0%, depending on development stage, botanical composition, soil type, K status of the soil and fertilizer application. The response of herbage growth to K application depends on the amount of K available in the soil and on the supply of other nutrients, mainly N. High N application rates result in rapid herbage growth and hence in high K requirements. In general, the amount of K taken up from the soil reserves adapts within certain limits to the supply with N and other nutrients (Hopper & Clement, 1966; Chevalier, 1978; Kemp, 1971). This is illustrated for a loamy soil in Figure 9.
On grassland on sandy soils K uptake in the situation without K application varied between 50 and 380 kg ha^{-1} yr^{-1} (Van de Ven, 1990). Not enough information was available to quantify the influence of N supply on K uptake in such situations. Therefore, in the model K uptake without K application has been assumed a constant and, on the basis of a literature review, has been estimated at 175 kg ha^{-1} yr^{-1} (Van de Ven, 1990). However, it should be kept in mind that the supply by the soil will decrease rapidly, if it is not replenished regularly.
The fertilizer advice given by the Dutch extension service aims at conserving a 'sufficient' K-status of the soil. At a high K-status, K application rate is decreased and at a low status it is increased until the K-status is sufficient again. Therefore, in the model, the average K application rate is calculated for a sandy soil with a sufficient K-status. The average K recovery on sandy soils has been estimated at 0.70 (Van de Ven, 1990).
If K is not limiting production, K application results in a high K content in herbage, because of continuing K uptake (Clement & Hopper, 1968). From the literature review it was concluded that a maximum K/N ratio in herbage, attained in field trials, was 1.4 (Van de Ven, 1990). A high K content is associated with a low Mg content and a low absorption efficiency of Mg by dairy cattle. This effect is intensified by a high N content. Mg deficiency in dairy cattle can be prevented by feeding Mg containing concentrates or by dusting the herbage with calcine magnesite (Kemp, 1971). However, to prevent unnecessary animal health problems, the K content of the herbage, and the corresponding K application rate, should not exceed those required for maximum yield levels.

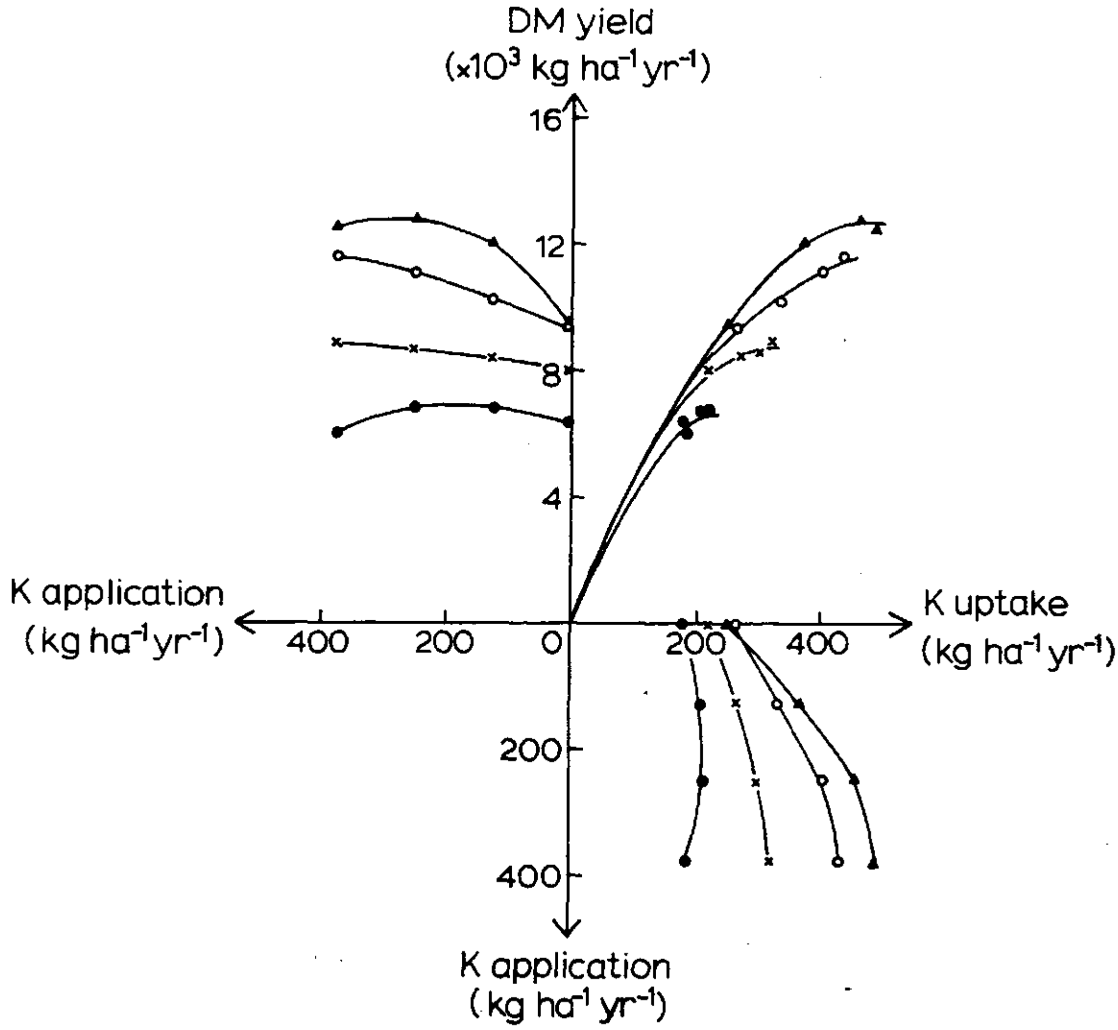

Figure 9. **The relation between K application rate, K uptake and dry matter yield of grass at 4 N application rates: 106, 191, 320 and 450 kg ha^{-1} yr^{-1} (after Chevalier, 1978).**

Based on work by Sluijsmans (1963) a relation between the N content of herbage and the K content required to prevent a yield reduction and to prevent animal health hazards, further referred to as the optimum K content, was derived (Commission Research of Mineral Supplies, 1990):

$$\%K = (47.75 * \%N + 158.2) / 100$$

This relation holds for N contents between 1 and 5%. A K content exceeding the optimum one indicates an excessive K availability. A lower K content indicates K deficiency and may result in a yield reduction. The relation described is used in the model to calculate the optimum K content. The actual K content is calculated from the amount of K available from the soil and fertilizers and the K recovery, similarly to the N content.

The main loss of K to the environment occurs by leaching. The amount of K leached below the rooting zone depends on the K status and the adsorption capacity of the soil, the rainfall surplus, K uptake by the herbage and fertilizer application. Reported K-leaching losses from grassland on sandy soils range from 20 to 280 kg K ha^{-1} yr^{-1}, with an average of 83 ha^{-1} yr^{-1} (Van de Ven, 1990). The maximum K concentration allowed in drinking water according to the EC norms is 12 mg l^{-1}. The rainfall surplus being approximately 300 mm, K leaching should not exceed 36 kg ha^{-1} yr^{-1}. On some sandy soils in the Netherlands K concentration in the upper groundwater exceeds the EC norm 2 to 4 times (De Wit & Bleuten, 1986). However, not enough data were available to quantify a relation between K application rate and leaching.

4 Quantification of the nitrogen flow on grassland

When running the model, first the system characteristics are specified by the user: grassland utilization method (G), N fertilizer application (NFERT), cutting percentage (MP), milk production per cow (MILK) and concentrate level (C) (Section 2.2). The units and the meaning of the variable names used in the model are given in the list of acronyms (Appendix 1).

4.1 Nitrogen application, nitrogen uptake and herbage production

The base N uptake (BASNUP) is calculated from N deposition (NDP) and N available from decomposition of organic matter (NOM), the fraction of N that is available in the growing season (MAXDP, MAXNOM) and the N recovery at a low N availability (NRECI). The values for each are given in the preceding chapter. The relation between N application and N uptake from fertilizers (NUPFER) is derived from Figure 9, taking into account that the first 150 kg N uptake originates from other sources (BASNUP). The relation is defined as a set of data, representing discrete points on the curve (the array TNUPF). Between consecutive values the value is calculated by linear interpolation, using the AFGEN function (Rappoldt & Van Kraalingen, 1990). Total N uptake (NUPDMT) is the sum of both BASNUP and NUPFER.

BASNUP = (MAXDP * NDP + MAXNOM * NOM)* NRECI (kg N ha^{-1} yr^{-1})
NUPFER = AFGEN(TNUPF,14,NFERT) (kg N ha^{-1} yr^{-1})
NUPDMT = BASNUP + NUPFER (kg N ha^{-1} yr^{-1})

Dry matter production associated with that N uptake (DMGMAX) is derived from Figure 5. The grassland utilization method determines which of the curves are used. For grazing the line pertaining to 1 700 kg ha^{-1} is used, for zero grazing the line pertaining to 2 300 kg ha^{-1} and for cutting herbage for conservation the line pertaining to 3 000 kg. If part of the production is conserved for winter feeding, combination of lines is required to calculate total annual dry matter production. This is done in the following way. All three curves are defined as arrays (TNDM1, TNDM2, TNDM3). The amount of dry matter conserved for winter feeding (DMC) is calculated from the cutting percentage (MP). Subsequently, total dry matter production is calculated for the situation with only cutting for conservation (DMCMAX) and for that with only grazing or zero grazing (DMGMAX).

DMC = 0.01 * MP * C3 (kg ha^{-1} yr^{-1})
DMCMAX = AFGEN(TNDM3,30,NUPDMT) (kg ha^{-1} yr^{-1})
DMGMAX = AFGEN(TNDM1/2,30,NUPDMT) (kg ha^{-1} yr^{-1})

The ratio DMC/DMCMAX reflects the proportion of the N taken up by grass for silage (NUPDMC) and the remainder of the total uptake is allocated to freshly consumed herbage (NUPDMG). Next, the actual amount of herbage consumed freshly is obtained by multiplying the calculated potential dry matter production, by its share in total N uptake. Total gross herbage production (DMT) is then calculated by adding the amounts of herbage for fresh consumption and for conservation:

NUPDMC = DMC/DMCMAX * NUPDMT (kg N ha^{-1} yr^{-1})

NUPDMG = NUPDMT - NUPDMC (kg N ha^{-1} yr^{-1})

DMG = NUPDMG/NUPDMT * DMGMAX (kg ha^{-1} yr^{-1})

DMT = DMG + DMC (kg ha^{-1} yr^{-1})

Subsequently, the N contents of freshly consumed and conserved grass are calculated.

CNDMG = NUPDMG/DMG (kg N kg^{-1} dm)

CNDMC = NUPDMC/DMC (kg N kg^{-1} dm)

Not all herbage produced can be consumed by the dairy cows, due to harvesting, grazing and feeding losses. Under day-and-night grazing the losses are 20% of the gross herbage production, under daytime grazing 14% and under zero grazing including cutting 7% (GHLDMG; Pelser, 1988). Harvesting and conservation losses for ensiling are 10% (HLDMC). Feeding losses of fresh grass in the stable are 2% (FLDMG;Pelser, 1988). Herbage available for consumption by dairy cows is:

DMGDG = (1 - GHLDMC) * (1 - FLDMG) * DMG (kg ha^{-1} yr^{-1})

DMCDC = (1 - HLDMC) (1 - FLDMC) * DMC (kg ha^{-1} yr^{-1})

The indoor feeding losse are added to the slurry reservoir. For pre-wilted silage this is taken into account in the winter period.

4.2 The nutritive value of herbage

The nutritive value of herbage is calculated in the subroutine FEED. It is expressed both in energy and in protein feeding value, the latter according to the new Dutch protein valuation system (CVB, 1990; IKC, 1991).

4.2.1 The energy content of herbage

The gross energy value (GE) of feeds can be measured directly as the combustion heat in a hot-air stove or it can be calulated from the chemical composition of the feed by using an empirically based regression equation. The metabolic energy value (ME) is the difference between the gross energy intake and the excretion of energy in faeces, urine and gasses, in ruminants mainly methane, and is calculated from the chemical composition of the feed. The net energy value (NE) is the part of the metabolic energy that is actually used for maintenance and production (Figure 10).

The energy losses depend on the composition of the feed, the digestibility, type of animal, type of product (milk or meat) and the feeding level. The influence of type of animal, type of production and feeding level are predictable and are implicitly taken into account in the valuation of the various feeds. For dairy cattle the net energy value of feeds is expressed as net energy for lactation (NEL) in kJ per kg dry matter.

The NEL value of herbage (MJ) is calculated from the metabolic energy (ME) and the gross energy (GE) content of the forage. The gross energy content of herbage does not vary very much and is set to 18410 kJ kg^{-1} dm (Van Es, 1978).

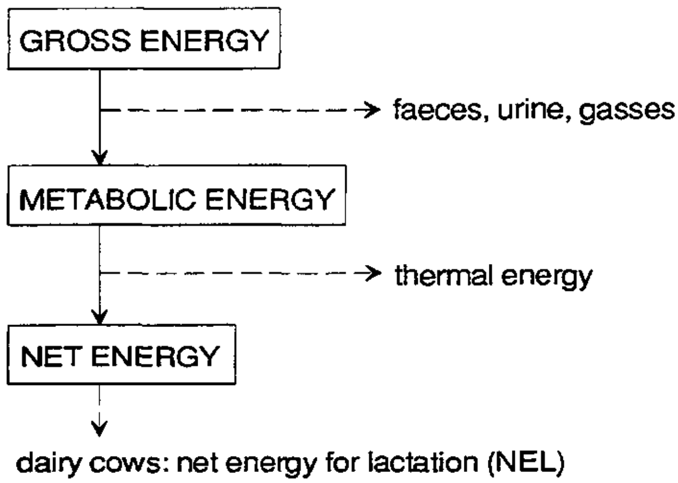

Figure 10. Scheme of energy flows in feed digestion and utilization.

The metabolic energy content depends on the digestible organic matter content (DOM) and the digestible crude protein content. DOM can be assessed by measuring the in-vitro digestibility or it can be calculated from the crude fiber content (CF), crude ash content (CASH) and, if grass is ensiled, dry matter content (DM), using an empirically based regression equation (Corporaal and Steg, 1990). Digestible crude protein is expressed as feeding standard crude protein (DCP) and is calculated from the crude protein content using a similar type of regression equation (CVB, 1977). For harvesting after 15 July a correction factor, depending on harvesting date, has to be applied. An average correction factor for season influences was calculated, which is given by the last figure in the equations below.

$CP = 6.25 * CN * 1000$ $\quad$ (g kg^{-1})

Fresh grass:

$DCP = 0.959 * CP + 0.04 * CASH - 40 - 2$ $\quad$ (g kg^{-1})

$DOM = 1058 - 0.74 * CF - 1.12 * CASH - 63$ $\quad$ (g kg^{-1})

Grass silage:

$DCP = 0.895 * CP + 0.04 * CASH - 40 - 5$ $\quad$ (g kg^{-1})

$DOM = 1063 - 0.77 * CF - 1.23 * CASH - 0.03 * DM - 54$ $\quad$ (g kg^{-1})

$ME = 14.23 * DOM + 5.86 * DCP$ $\quad$ (kJ kg^{-1})

$Q = 100 * ME/GE$ $\quad$ (kJ kg^{-1})

NEL = $MJ = (0.6 * (1 + 0.004 * (Q - 57)) * 0.9752 * ME) / 1000$ $\quad$ (MJ kg^{-1})

Using the equations and data described above, the net energy value of the herbage in PAW 970 is calculated. DCP was calculated from the N content in the herbage. The CF and CASH of the herbage in PAW 970 were unknown and had to be estimated.

The crude ash content varies with the N content of the herbage and with harvesting frequency. The crude fiber content increases with the age of the herbage, but is hardly influenced by the N application rate (Van Vuuren et al., 1991). However, if the period required to reach a harvestable cut exceeds 4 to 5 weeks due low fertilizer levels, the crude fiber content starts to increase (Vellinga, 1992).

The CVB (1991) only gives the values of crude fiber and crude ash content at a herbage yield of 1 700 kg ha^{-1} and for herbage ensiled. For estimating the crude ash and crude fiber content at 2 300 kg ha^{-1} additional information is necessary, which is based on the model GRAMIN as developed by Vellinga (pers. comm.). The annual average values for crude fiber and crude ash contents as influenced by N content and harvesting frequency are given in Table 5. The variation in N content according to the CVB is the result of variation in N application rates (200 - 400 kg ha^{-1} yr^{-1}). The CVB has based their figures on GRAMIN and as the relation between N uptake and herbage yield in GRAMIN differs somewhat from that in GRASMOD all data are related to N content instead of N application rate.

Table 5. Annual average values for the crude fiber (CF) and ash content (CASH) and the energy value of herbage as influenced by N content and harvesting frequency according to the CVB (1991) and to the model GRAMIN.

herbage yield (kg ha^{-1})	source	content in dry mass (g kg^{-1})			NEL (kJ kg^{-1})
		N	CF	CASH	
1700	CVB	30.4	210	93	6680
		33.2	204	96	6770
		36.4	203	98	6840
2300	GRAMIN	29.0	219	90	6665
		31.6	222	94	6720
		34.8	215	97	6755
		37.1	216	98	6820
ensiled	CVB	28.6	245	112	5755
		31.9	242	115	5830
		34.8	240	118	5870

Based on both data sets the crude fiber and crude ash content are estimated as follows:

1700 kg dm ha^{-1}:	CF = 205	(g kg^{-1})
	CASH = 0.9 * N + 65	(g kg^{-1})
2300 kg dm ha^{-1}:	CF = 215	(g kg^{-1})
	CASH = 0.9 * N + 60	(g kg^{-1})
conserved herbage:	CF = 245	(g kg^{-1})
	CASH = 0.9 * N + 86	(g kg^{-1})

The feeding value calculated with these values for crude fiber and crude ash are rather close to the values according to GRAMIN and the CVB, as is shown in Figure 11.
Wieringa et al. (1980) reported an average NEL value of herbage for each N application rate in PAW 970. This was an average over two years and applies to varying, but mostly low, yields per cut. In Figure 11 these average values are compared with the calculated ones for harvesting at 1 700 and 2 300 kg ha^{-1} yr^{-1}. It was not possible to derive the energy values for different yields from the data reported by Wieringa et al. (1980).
In GRASMOD the period required to obtain a harvestable cut when no N fertilizer is applied exceeds 4 to 5 weeks (Tabel 2) and thus the feeding value is probably slightly overestimated in this case. Regarding the mostly low yields per cut in PAW 970, the rather small differences between calculated and standard energy values (CVB, 1991), and the required range for estimating the nutritive value of the herbage, the calculated values are applied in GRASMOD.
In GRASMOD the season is split into two periods with regard to milk production of the dairy cows: before 15 July and after 15 July. For both periods the nutritive value of the herbage has to be estimated.

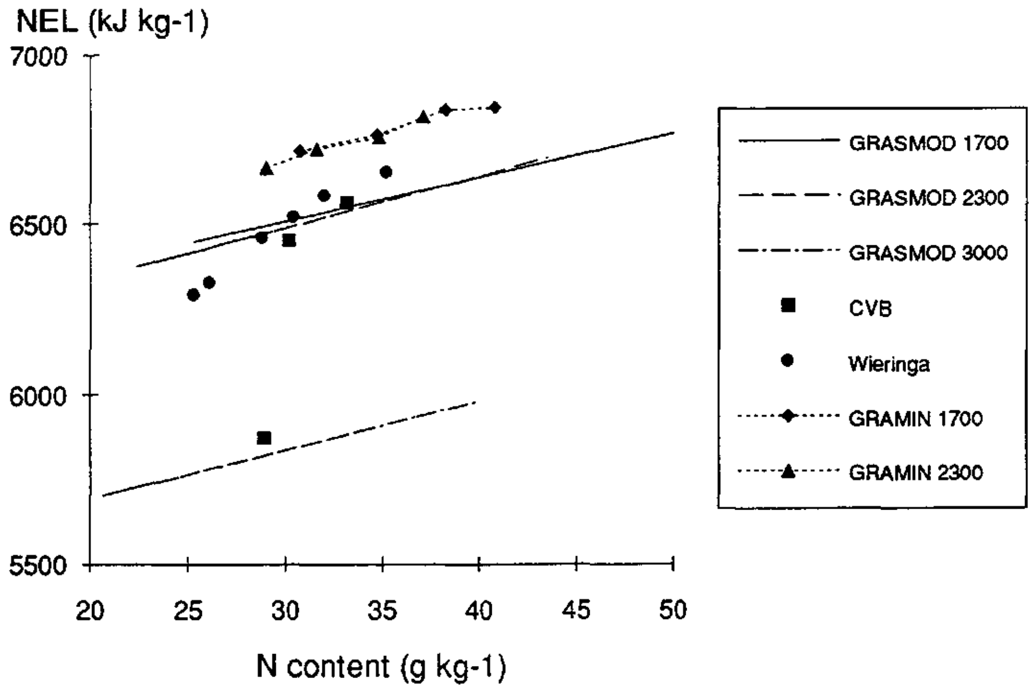

Figure 11. **The relation between the N content and energy value of herbage (NEL) for three harvesting frequencies, according to GRAMIN, CVB, Wieringa and as estimated in GRASMOD.**

In the Standards for Forage Supply (Werkgroep Normen voor de Voedervoorziening, 1991), the season is split into four periods: the first cut, from the first cut to 1 July, 1 July to 1 September and after 1 September. From these data the average nutritive value before and after 1 July is calculted and given in Table 6.

Table 6. *The relation between the N application rate and average nutritive value of herbage in NEL before and after 1 July (Werkgroep Normen voor de Voedervoorziening, 1991).*

N application	NEL (kJ kg^{-1})	
(kg ha^{-1} yr^{-1})	until 1 July	after 1 July
200	6840	6550
300	6920	6620
400	7000	6660
500	7060	6765

This Table shows that, indepently of the N application rate, the difference in the nutritive value between the two periods is approximately 310 kJ. In the subroutine Feed an average nutritive value for the whole growing season is calculated, as the available data do not allow a more detailed estimation. The harvesting date is set to 1 July, as at that moment the nutritive value of the herbage approaches the average annual value (Werkgroep Normen voor de Voedervoorziening, 1991). Subsequently, in the subroutine DIET, in which the feed ration of the dairy cows is calculated, 155 kJ is added to this value for the first period and 155 kJ is subtracted from it for the second period. For conserved herbage no distinction is made for the nutritive value in the two periods, as it is assumed that this herbage is mixed when fed.

4.2.2 The protein feeding value of herbage

In 1991 a new system for calculation of the protein feeding value of feeds has been introduced in the Netherlands (CVB, 1990; IKC, 1991).
This system quantifies the supply of digestible protein to the intestine and the protein surplus in the rumen by means of the intestinally digested protein (DVE) and the rumen degraded protein balance (OEB). It is based on a combination of the French, the American and the Scandinavian feed valuation systems.
The intestinally digested protein originates from two sources. The enzymatic activity of microbes in the rumen results in a breakdown of the rumen degradable protein. The products of this process are incorporated into microbial protein. The microbial protein is transported together with the partially digested feed to the intestine, where the proteins are broken down into amino acids and taken up by the blood to be used for maintenance, growth and milk production.
Formation of microbial protein not only depends on the availability of rumen degraded protein, but also on the availability of energy from the feed. The OEB value of a feed indicates the difference between the maximum microbial protein formation based on the availability of protein and that based on the availability of energy. If the OEB value is negative a N shortage exists and the calculted contribution of microbial protein to the DVE can not be guaranteed. A surplus of rumen degraded protein is converted to ammonia, transported by the veins to the liver, converted to urea and finally, excreted with urine. Thus the OEB should be as close to zero as possible.
Using this new system, the protein supply and requirement can be matched more effectively and doing so, the N utilization by the animal can increase.
To calculate the protein feeding value of herbage according to the new system the formulas as given by the CVB (1991) are used in GRASMOD:
Fresh grass:

PBRE	= 38.6 - 0.08 * CP + 0.07 * DAY	(-)
PRRE	= 10.2 - 0.037 * CP + 0.022 * DAY	(-)
DAY	= 91	

DAY is a factor that takes the influence of the harvesting date into account and is calculated as the number of days after 1 April. For freshly consumed herbage the average harvesting date is set to 1 July, and for herbage for conservation to 1 June.
Conserved herbage:

PBRE	= 28.6 - 0.09 * CP + 0.051 * DAY + 0.028 * DM	(-)
PRRE	= 19.4 - 0.061 * CP + 0.030 * DAY	(-)
FP	= 170 - 0.3 * DM + 2 * NH3-fraction	(-)
DAY	= 61	
DM	= 350, dry matter content of herbage	(g kg^{-1})

NH3-fraction: should be at least 15; as this is a rather high value, it is set to this minimum value.

PDVE	= (PBRE - PRRE)/PBRE * 100	(-)
DVBE	= 1.1 * (CP * PBRE/100) * (PDVBE/100)	(g kg^{-1})
FOS	= DOM - CFAT - CP * (PBRE/100) - FP*0.5	(g kg^{-1})

DVME = FOS * 0.150 * 0.75 * 0.85 $(g\ kg^{-1})$
DVMFE = (1000 - DOM - CASH * 0.5) * 0.075 $(g\ kg^{-1})$
DVE = DVBE + DVME - DVMFE $(g\ kg^{-1})$
CFAT = 40 $(g\ kg^{-1})$
OEB = CP * (1 - 1.11 * PBRE/100) - FOS * 0.150 $(g\ kg^{-1})$

The protein feeding value is not calculated for the two periods separately, because the DVE value hardly changes during the growing season (Werkgroep Normen voor de Voedervoorziening, 1991)

The results of the calculations in GRASMOD are compared to those calculated in GRAMIN and given by the CVB (1991) are presented in Figure 12. For both freshly consumed herbage and conserved herbage, the relation between N content and DVE (Figure 12 a) and N content and OEB (Figure 12 b) are similar.

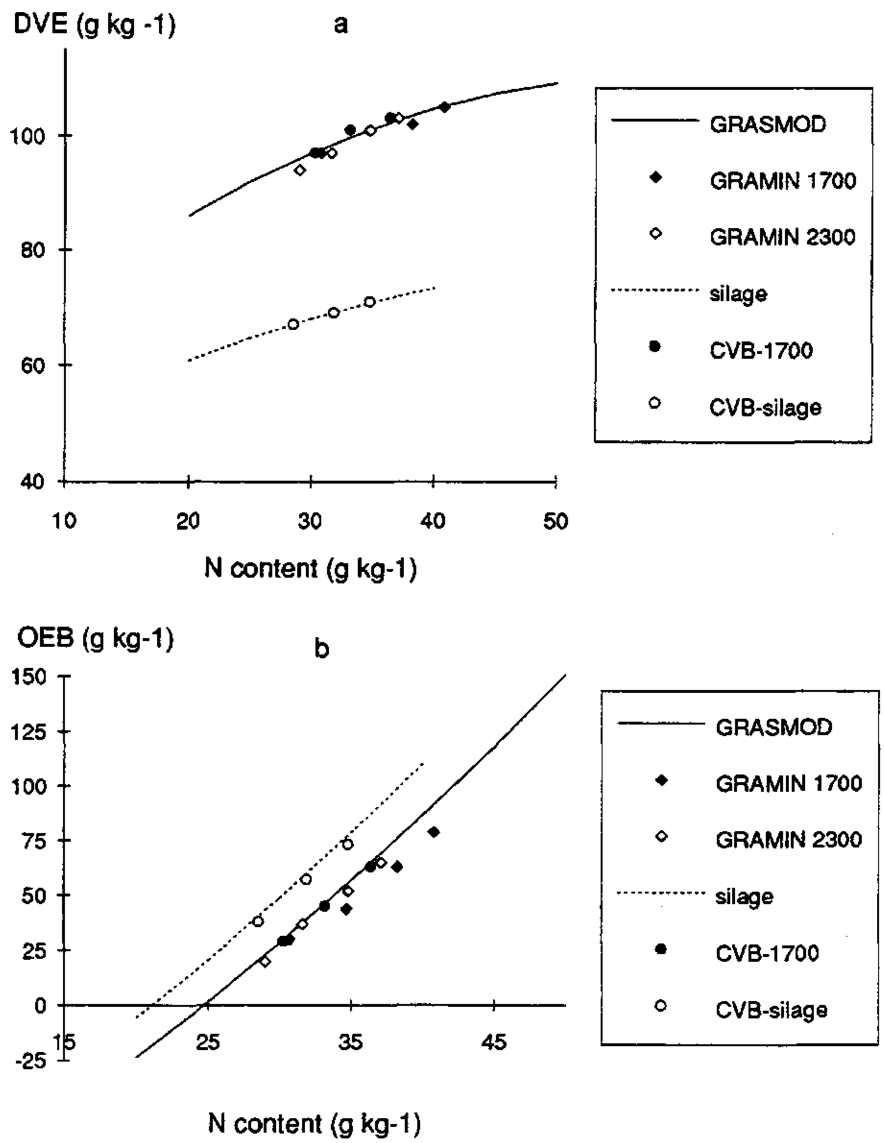

Figure 12. a. The relation between N content and the DVE value of herbage according to GRASMOD and GRAMIN.
b. The relation between N content and the OEB value of herbage according to GRASMOD and GRAMIN.

4.3 Feed ration of the dairy stock

The feed ration of the dairy stock is based on grass and, depending on the grazing system, silage maize. Concentrates, are only used as a supplement to arrive at the required amount of energy and protein. Under daytime grazing, 4.5 kg of silage maize is fed during the night in the stable, representing on average one third of the energy requirements. This is a rather arbitrary value which can easily be changed. In general, farmers do not supply grass during the night, when applying the system of daytime grazing. They save grass silage for the winter period, as grass is protein-rich and thus combines well with silage maize, which is energy-rich. By feeding silage maize during the night the N content of the ration is reduced, which leads to lower N excretion in urine and thus may reduce N losses to the environment. Under day-and-night grazing no silage maize is fed. Under zero grazing both rations, with and without silage maize, can be choosen to facilitate comparison of the effect of keeping cows indoors all year round with both grazing systems.
The energy and protein requirements and the supply with the various feed stuffs are calculated in the subroutine DIET.

4.3.1 Energy requirements

The dairy stock requires energy for maintenance, milk production, pregnancy and, for young cows, weight gain. The energy requirements for maintenance depend on the weight of the cow. For a cow of 600 kg the maintenance requirements are 34 630 kJ per day (Hijink & Meijer, 1987).
The energy requirements for milk production are calculated for cows producing 5 000, 6 500 and 8 000 kg milk per year. During the lactation period the milk production changes. The relative distribution of the milk production over the lactation period, as is given by Rompelberg et al. (1984), which is a biweekly average, is used to calculate the milk production per day. Cows calving at the beginning of February produce 53.5% of the milk during the summer (1 May - 1 November, 184 days) and 46.5% during the winter period (181 days). However, one average daily milk production during the summer and the winter underestimates the energy requirements in the beginning of the lactation and overestimates them at the end of the lactation. Therefore, the year has been divided in five milk production periods, two during the summer and 3 during the winter season (Figure 13).
During pregnancy energy is required to form a calf and to maintain a somewhat higher liveweight of the cow.
The additional energy requirements for growth of cows in their first and second lactation are 4 145 and 2 070 kJ cow^{-1} d^{-1}, allowing weight gains of 53 and 26 kg per cow per year, respectively. In the average dairy stock 22% of the cows are in their first lactation, 18% in the second one and 60% in the third or more. Such a herd composition requires on average 1 285 kJ per cow per day for weight increase (Hijink & Meijer, 1987).
Additionally, energy is required for grazing, walking, digesting a protein surplus and compensating an unregular intake. Those requirements differ for the various grassland utilization methods. The energy allowance for cows grazing day and night is 7 320 kJ per cow per day, for cows grazing during the day time only 6 420 kJ per cow per day and for zero graszing 1 590 kJ per cow per day (Hijink & Meijer, 1987). In the winter period all cows are indoors and the requirements are identical for all three grassland utilization methods.

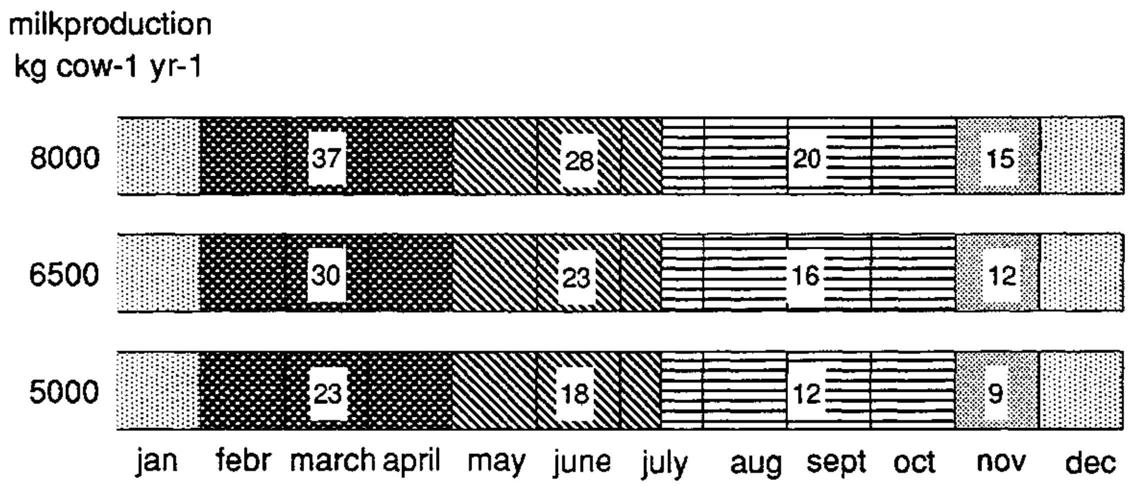

Figure 13. Milk production in kg cow^{-1} d^{-1} during five periods for three annual milk production levels.

In GRASMOD the energy requirements are calculated for each period separately, using following the equations (Hijink & Meijer, 1987):

maintenance: ENRM = 9 760 + 41.45 x W = 34 630 (kJ cow^{-1} d^{-1})
milk production: ENRP = 3 040 * MILKD + 5.04 * MILKD^2 (kJ cow^{-1} d^{-1})
pregnancy: ENRC = 121 * $e^{0.0174*t}$ (kJ cow^{-1} d^{-1})
weight gain: ENRG = 1 285 (kJ cow^{-1} d^{-1})
W : liveweight of the cow (600 kg) (kg)
MILKD: milk production per cow (kg d^{-1})
t : number of days pregnant (d)

In the first period after calving (1 Febuary - 1 May), the energy requirements cannot be met, because of physiological limits on dry matter intake. The weight of the animal decreases due to mobilization of reserves and this is compensated for during the summer period. The dry matter intake capacity of dairy cows depends on the milk production level. At a higher production level the intake capacity increases, but the energy requirements increase more than proportionally. Based on Hijink & Meijer (1987) and IKC (1991), it is assumed that at milk production levels of 5 000, 6 500 and 8 000 kg milk per cow per year 2.5, 5.0 and 7.5% of the energy requirements during the first period after calving have to be supplied during the summer periods. This additional energy requirement during the summer is distributed proportionally over the two periods and amounts to 1 310, 3 180 and 5 620 kJ per day for cows producing 5 000, 6 500 and 8 000 kg milk per year, respectively.
The influence of the assumption that all cows calve at the beginning of february is small. The energy requirements per period are calculated in the same way for the calving date of 1 august. The maximum difference in energy requirement is 1.9% in the summer period for cows producing 6 500 kg milk yr^{-1}. The part of the total energy requirements that can be met by herbage and silage maize differs somewhat, but this is not yet taken into account in GRASMOD.

4.3.2 Protein requirements

The DVE requirements of dairy cows are calculated for each period separately, using the following equations (CVB , 1990):

maintenance:	dve = $(2.75*W^{0.5} + 0.2*W^{0.6})/0.64$	(g cow^{-1} d^{-1})
milk production:	dve = (milkproduction*protein content)/0.64	(g cow^{-1} d^{-1})
pregnancy:	dve = 60 during the sixth month of pregnancy	(g cow^{-1} d^{-1})
weigth gain:	dve = 0.22*34 + 0.18*17	(g cow^{-1} d^{-1})

For a cow of 600 kg 114 g DVE d^{-1} is required for maintenance. The protein content of milk is set to the standard value of 33 g kg^{-1} and thus daily the DVE requirement is 52x the daily milk production. For pregnancy only during the last month of the grazing season 60 g DVE d^{-1} is required. Converted to an average requirement per day over the whole second summer period this amounts to 13 g DVE cow^{-1} d^{-1}. Weight gain only applies to the cows that still have to grow. The DVE requirements are 34 g DVE cow^{-1} d^{-1} for 22% of the herd and 17 g DVE for 18% of the herd. The liveweights of dairy cows in their first and second lactation is respectively 500 and 550 kg. The average DVE requirements of the herd are thus:

DVERM = 0.22*(104 +34) + 0.18*(109 +17) + 0.60*115 = 121	(g cow^{-1} d^{-1})
DVERP = 52*MILKD	(g cow^{-1} d^{-1})
DVERC = 13	(g cow^{-1} d^{-1})
DVERT = DVERM + DVERP + DVERC	(g cow^{-1} d^{-1})

4.3.3 Feed intake

The feed intake is calculated according to the cow model developed by Hijink and Meijer (1987). Most of the realations in this model are derived for a cow producing 6 000 kg milk per year, consuming 15 kg of herbage per day during the summer period under day and night grazing, and for herbage and silage maize with an average energy content. Subsequently, the relations are adapted for other production levels, grazing systems and energy contents. The feed intake of dairy cows (MAXI) is limited and depends on milk production level, lactation stage and energy content of the feed. The lactation stage is taken into account by a factor R that indicates forage intake relative to the maximum intake. The relative forage intake is given in Figure 14 (Hijink & Meijer, 1987). In the model the curve is flattened out at 100%. For the first summer period R is set to 1 and for the second one to 0.95.

MAXI = 1.1*(4.965 + 1.38 * MJDMG) * (0.6 + MILK/15 000) * R	(kg cow^{-1} d^{-1})
MJDMG: energy content of herbage	(MJ kg^{-1})
R : factor for the lactation stage	(-)

The equation described is derived for day and night grazing. Under day grazing only and zero grazing the energy requirements and the maximum intake are lower and a correction factor is introduced (FSYS). The maximum dry matter intake becomes:

DMIMAX = MAXI * FSYS		(kg cow^{-1} d^{-1})
day and night grazing	: FSYS = 1	(-)
day grazing only	: = 0.9	
zero grazing	: = 0.87	

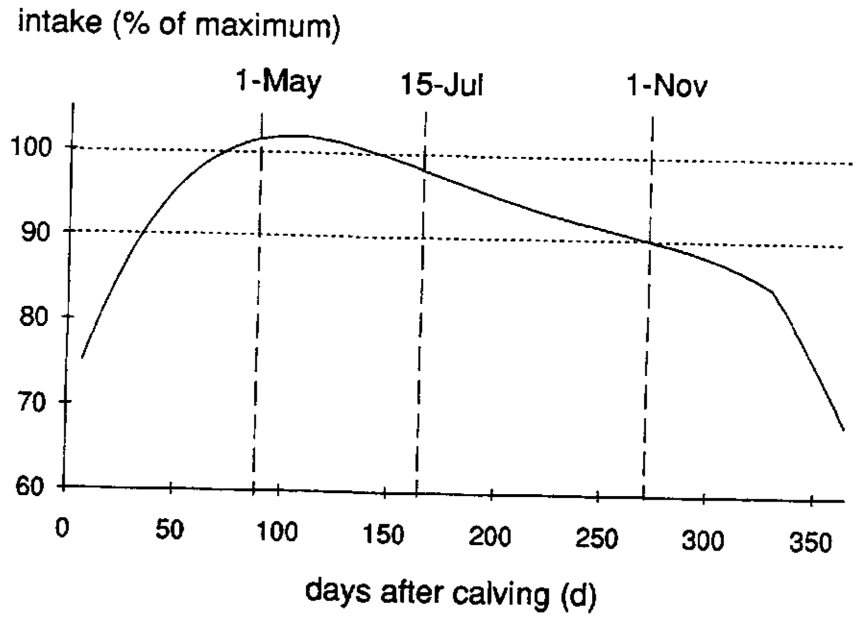

Figure 14. The forage intake for dairy cows during the laction period relative to the maximum intake.

Grass combined with other roughages, will partly be replaced. The replacement rate (RM) depends on the difference in energy content between grass and the other forage crop, the maximum dry matter intake, and the milk production level. In GRASMOD, silage maize is the only other forage. Subsequently, the herbage intake (GIDC) is calculated by correcting the maximum intake for the silage maize intake (MAIDC).

RM = (0.133 * DMIMAX/MAXI * 15 - 1.013) * MJDMG/6.56 * 6.22/MJMAIS * (1/(0.6 + MILK/15 000)) (-)

GIDC = DMIMAX - RM * MAIDC ($kg\ cow^{-1}\ d^{-1}$)

MJMAIS = 6.22 ($MJ\ kg^{-1}\ dm$)

If the energy requirements are not met by the herbage and maize intake, additionally, concentrates have to be supplied. However, also concentrates replace part of the forage. The replacement by concentrates (RC) depends on the amount fed (CVB, 1991):

concentrate intake	0.0 - 3.5 kg dm $cow^{-1}\ d^{-1}$:	RC = 0.3	($kg\ kg^{-1}$)
	3.5 - 7.0 „ :	RC = 0.5	($kg\ kg^{-1}$)
	7.0 < „ :	RC = 0.7	($kg\ kg^{-1}$)

The total amount of energy intake is calculated in such a way that the requirements (ENRDCS) are just met:

GIDC * MJDMG + MAIDC * MJMAIS + COIDC * MJCON = ENRDCS ($MJ\ cow^{-1}\ d^{-1}$)

MJCON = 7.43 ($MJ\ kg^{-1}\ dm$)

The feed ration should contain a sufficient amount of fibrous material not to hamper digestion of the feed. In the Dutch feeding standards a 'structural value' is attached to all feed stuffs and the total value of the ration (SW) should not drop below 0.33. For herbage the structural value per kg dry matter is 0.55 (SWG), for silage maize 0.65 (SWM) and for concentrates 0.

SW = (GIDC * SWG + MAIDC * SWM) / (GIDC + MAIDC + COIDC) (-)

The feed ration should meet the protein requirements, but the protein surplus should be limited. The DVE and OEB values of herbage are calculated in the model and for maize silage they are set to average values. If the concentrate type is set to the standard value (CT=0), two types of concentrates are available, C1 and C2 (Table 7). The feeding values for C1 are similar to those for ground earmaize. C2 is a standard concentrate with a low protein feeding value, because herbage, which is the main component in the feed ration, has rather high DVE and OEB values (Beukeboom et al., 1991). Only herbage grown at low fertilizer levels has low OEB values. The combination of C1 and C2 is calculated in such a way that the DVE requirements are met and the surplus is minimal. If the resulting OEB balance is negative, C1 is replaced by C2. This increases the OEB balance, but also the DVE surplus. Even if the OEB balance is still negative, it is assumed that the DVE requirments can be met, because a DVE surplus exists. In such situations it does not matter if the potential DVE value is not realized due to overestimation of the contribution of microbial protein to the DVE value (Section 4.2.2).

If the adjusted concentrate mixture is choosen (CT=1), four types of concentrates are available. C1 can be replaced by C4 and C2 by C3 to be able to get closer to the feeding standards without over-consumption of protein. The N content of the feed ration can be reduced and the N utilization by the animals can increase. The feeding values of the four types of concentrates are given in Table 7. The energy value is set ot the same value for all four types of concentrates.

Table 7. Characteristics relevant for the protein feeding value of the four types of concentrates, C1 to C4, in g kg^{-1} dm.

concentrate type	C1	C2	C3	C4
DVE	64	100	100	60
OEB	-20	20	-20	20
N content	14	29	23	22
cp content	85	190	145	135
dcp content	55	145	95	95
digestibilty coefficient	0.65	0.75	0.65	0.70

The daily feed ration is calculated for both the summer periods separatly. At the end of the subroutine DIET the total intake of herbage, silage maize and concentrates during the whole summer period is calculated.
The feed intake during the winter period is calculated in the linear programming procedure and not in GRASMOD.

4.4 Influence of grazing

Under zero grazing all faeces and urine are collected indoors. The slurry can be spread relatively homogeneously at a well-timed moment, using application methods with low ammonia losses. However, under grazing faeces and urine are deposited very heterogeneously and timing and emissions can not be influenced. The N load in urine and faeces patches has been estimated as a function of N intake and milk and meat production. It has been assumed that urine-N, available for uptake by plants, has similar effects as fertilizer application. Thus, in urine patches N uptake and herbage production are higher than in interjacent areas. In faeces patches no additional herbage is produced. It has been assumed that the increased production at the edge of faeces patches, is offset by the decrease in production due to covering by faeces, which completely prevents herbage growth during some time (Deenen, pers.comm.; Middelkoop, 1989). To quantify the effects of grazing on the N fluxes in grassland, additional calculations and assumptions have been made as described in this section.

4.4.1 Cow grazing days

The stocking rate (SR) is calculated from the net amount of herbage available (DMGDC) and the total amount required by the dairy cows during the summer period (GIDCS). Subsequently, the stocking rate determines the number of cow grazing days realized on one ha. A cow grazing day is defined as one cow grazing one day in a day-and-night grazing system. It has been assumed that milking takes two hours each time and hence, during one cow grazing day, cows are on pasture 20 out of 24 hours. For daytime grazing it has been assumed that the grazing period is half that for day-and-night grazing. Therefore, one cow grazing one day under daytime grazing equals 0.5 cow grazing days.
The number of real grazing days (RGD) is converted into cow grazing days (D) by multiplying RGD by a grazing factor (GF). This conversion allows for the use of the same procedure for calculation of the influence of grazing for both grazing systems. For zero grazing the grazing factor is 0, for day-and-night grazing 1 and for daytime grazing 0.5. Hence:

SR = DMGDC / GIDCS (cows ha^{-1} yr^{-1})
RGD = SR * SP (d ha^{-1} yr^{-1})
D = RGD*GF (d ha^{-1} yr^{-1})
SP = 184 (d yr^{-1})

4.4.2 N intake and N excretion by dairy stock during the summer

N intake by the dairy stock during the summer period (NIDC) is calculated from the amount of herbage, silage maize and concentrates consumed and their respective N contents:

CONCS = COIDCS * SR (kg ha^{-1} yr^{-1})
MAISS = MAIDCS * SR (kg ha^{-1} yr^{-1})
NIC = CONCS * CNCON (kg N ha^{-1} yr^{-1})
NIM = MAISS * CNM (kg N ha^{-1} yr^{-1})
NIDC = CNDMG * DMGDC + NIC + NIM (kg N ha^{-1} yr^{-1})

N is incorporated in milk and meat (liveweight) and excreted with urine and faeces. The average N content of milk is 0.53% and that of meat 2.5% (Biewinga et al., 1987). The amount of N incorporated in milk and meat in the summer period (NPS) depends on stocking rate and on milk and meat production per cow. The remainder of the N is excreted in urine and faeces (NEXDC).

NPS = SR * (0.535 * MILK* 0.0053 + SP/365 * MEAT * 0.025) (kg N ha^{-1} yr^{-1})
NEXDC = NIDC - NPS (kg N ha^{-1} yr^{-1})

Distribution of the N excreted over faeces and urine influences type and amount of N losses. Excretion of N in faeces (NFT) is calculated from the fraction non-digestible crude protein and the dry matter intake of the various feeds. For grass the protein digestibility coefficient (PDCG) is calculated as the DCP/CP ratio of the grass (Section 4.2) and the fraction non-digestible crude protein as its complement. The average protein digestibility coefficient of silage maize (PDCM) is 0.56 (Pelser, 1988; CVB, 1991). The protein digestibility coefficient of the various types of concentrates depends on their N content (Table 7)

NFT = (GIDC * CNDMG * (1 - PDCG) + COIDC * CNCON * (1 - PDCC) + MAIDC * CNM * (1 - PDCM)) * RGD (kg N ha^{-1} yr^{-1})

CPG = 6.25 * CNDMG * 1000 (g kg^{-1})

FCPG = 0.959 * CPG + 0.04 * 95 - 40 - 2 (g kg^{-1})

PDCG = FCPG / CPG (-)

The part of NEXDC that is not excreted in faeces, is excreted in urine (NUT).

NUT = NEXDC - NFT (kg N ha^{-1} yr^{-1})

On average, dairy cows defaecate and urinate 12 times daily (Groenwold & Keunig, 1988; Vertregt & Rutgers 1988; Whitehead, 1986; MacDiarmid & Watkin, 1972; MacLusky, 1960). The N content of one defaecation (NFEXS) and of one urination (NUEXS), required for estimating the N load in the faeces and urine patches, is calculated next.

NUEXS = NUT / (12 * RGD) (kg N per excretion)

NFEXS = NFT / (12 * RGD) (kg N per excretion)

The amount of N voided at pasture (NUS, NFS) is determined by the N content per excretion and the number of excretions in the field, which depends on the grazing factor. It is assumed that the excretion of faeces and urine is spread regularly in time, so at the maximum 10 out of 12 excretions per cow grazing day (MF) are deposited in the field. The amount of N collected in slurry (NSLUR) is the difference between total N excreted and N voided at pasture. It is assumed that the loss of N during transfer between the field and the stable is negligible.

NUS = NUT * GF * MF (kg N ha^{-1} yr^{-1})

NFS = NFT * GF * MF (kg N ha^{-1} yr^{-1})

MF = 10/12 (-)

NSLUR = NUT + NFT - NUS - NFS (kg N ha^{-1} yr^{-1})

4.4.3 Distribution of urine and faeces in the field

The distribution of faeces and urine in the field is calculated in a subroutine DISTRI. It is assumed that faeces and urine are distributed at random in the field, hence disregarding concentration of excreta near watering-points and gates. In the field overlap of faeces and urine patches occurs, which can be accounted for by using a Poisson distribution (Petersen et al, 1956). The area covered x times with faeces or urine (P(x)) is estimated from the expectation value μ, i.e. the area that is covered without overlap. The value of μ depends on the total number of excretions and the surface area per excretion:

$\mu = 10 * D * AREA$ (-)

$P(x) = e^{-\mu} * \mu^x / x!$ (-)

The area affected is set at 0.68 m2 per urination and 0.08 m2 per defaeceation (Groenwold & Keuning, 1988, Vertregt & Rutgers, 1988; Whitehead, 1986; MAcDiarmid & Watkin, 1972). The Poisson distribution is used to calculate the areas not covered and covered once and twice with urine (U0, U1, U2) and with faeces patches (F0, F1, F2). Combinations of urine and faeces (F(i,j)) are calculated by multiplying the respective areas.

F(i,j) = U(i) * F(j) (-)

i = 0, 1, 2

j = 0, 1, 2

The grazing area is thus divided into nine parts covered less than three times with faeces or urine and a remaining part (FREST) covered three times or more. FREST is so small already that for the purpose of this study a further subdivision is not required.

$$FREST = 1 - \sum_{i=0}^{2} \sum_{j=0}^{2} F(i,j) \qquad (-)$$

In Figure 15 an example is given of the proportion of the ten field parts for one specific situation.

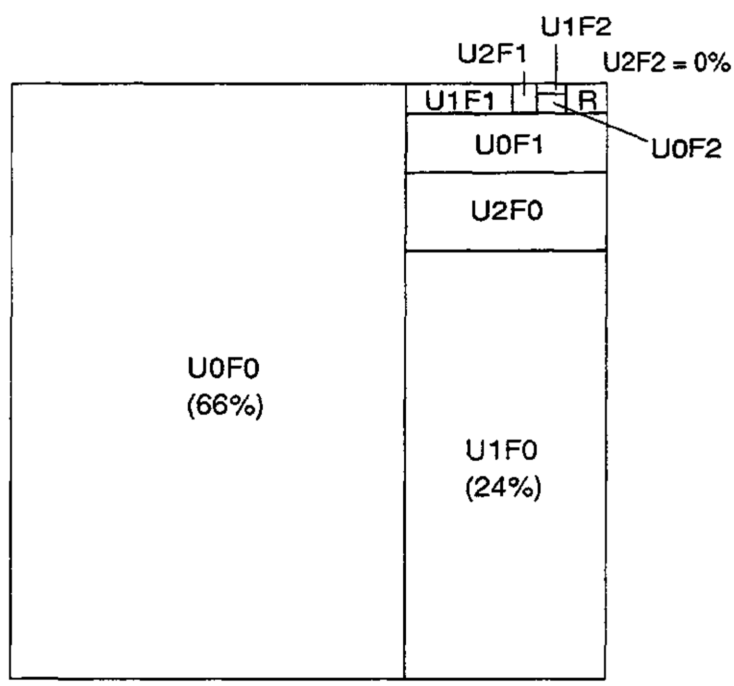

Figure 15. The proportion of the field parts F(I,J) and FREST for day-and night-grazing, at 250 kg N ha^{-1} yr^{-1}, no cutting for conservation, cows producing 6 500 kg milk yr^{-1} and the default stocking rate.

4.4.4 Herbage production and N uptake in the various field parts

For each of the ten field parts the N load by urine (NU(I,J)) and by faeces (NF(I,J)) is calculted in kg per ha urine/faeces patch. For technical reasons (division by 0) I and J vary from 1 to 3 in GRASMOD instead of 0 to 2. In the calculatations this is corrected.

NU(I,J) = NUEXS / AREAU * (I - 1) (kg N ha^{-1} yr^{-1})

NF(I,J) = NFEXS / AREAF * (J - 1) (kg N ha^{-1} yr^{-1})

Covering by faeces does not lead to additional N uptake or herbage production. From urine-N 13% volatilizes as ammonia, 27% is lost by unidentified processes, possibly chemo-denitrification, and the remaining 60% (MAXNUS) is available in inorganic form in the soil for plant uptake (Vertregt & Rutgers, 1988).

Urine is excreted throughout the growing season, but, assuming that inorganic N in urine is identical to fertilizer N, it has little effect on herbage growth, when voided in September/October. Experimental results (Van der Meer & Van Uum-van Lohuyzen, 1989;

Middelkoop, 1989; Van der Meer & Whitehead, 1990) indicated that on average, 30% of the N voided with urine was actually taken up during the growing season. This was 50% of the inorganic urinary N in the soil, available for pant uptake. Assuming the N recovery was 75%, comparable to that at fertilizer levels of 200 - 400 kg N ha^{-1} yr^{-1}, seasonal effects reduced the potential N uptake to 65% (50 / 75 * 100%) of the inorganic urinary N in the soil.
Considering the period in the growing season during which urine is present, and the period N application is effective, leads to a similar estimate. Assuming that the effect of urine N voided in the previous season is not carried over the winter period, no urine N is present during the growth period of the first cut. If it is assumed additionally that urine N is, similar to fertilizer N, hardly effective after 15 September then urine N can be taken up during 65% of the growing season (1 April - 1 November).
Hence, it has been assumed that seasonal effects reduce the amount of urine N, potentially available for plant uptake, to 65% (FUPSEA). This implies a maximum seasonal N uptake of 39% of the total N voided with urine (0.65 * 0.60 * 100%).
The total amount of inorganic N voided in urine patches (NM(I,J)) is the sum of fertilizer N and 60% of the N from urine. However, seasonal effects reduce the amount that can actually be taken up (NMC(I,J):

$$\mathrm{NM(I,J)} = \mathrm{NFERT} + \mathrm{MAXNUS} * \mathrm{NU(I,J)} \qquad (\mathrm{kg\ N\ ha^{-1}\ yr^{-1}})$$

$$\mathrm{NMC(I,J)} = \mathrm{NFERT} + \mathrm{FUPSEA} * \mathrm{MAXNUS} * \mathrm{NU(I,J)} \qquad (\mathrm{kg\ N\ ha^{-1}\ yr^{-1}})$$

$$\mathrm{FUPSEA} = 0.65 \qquad (-)$$

$$\mathrm{MAXNUS} = 0.60 \qquad (-)$$

For each of the ten field parts N uptake by herbage (NUP(I,J)) and herbage production (DMTT(I,J)) are calculated separately, similarly to the calculations for the area not influenced by urine and faeces, i.e. NMC(I,J) as the fertilizer application rate. Additional herbage production resulting from urine excretion is assumed to be grazed, as herbage is cut at 3 000 kg ha^{-1} and the cutting percentage is not adapted. However, the N content of the herbage both grazed and conserved is higher due to the additional N application with urine.

4.4.5 Average herbage production and N uptake per ha

So far, N uptake and herbage production have been calculated for all ten field parts separately in kg ha^{-1} yr^{-1}. To arrive at the averages per ha of land (NUPSUM, DMTSUM) the results are weighted according to their share in the surface area:

$$\mathrm{NUPSUM} = \sum_{i=0}^{2} \sum_{j=0}^{2} \mathrm{NUP(I,J)} * \mathrm{F(I,J)} + \mathrm{NUPRST} * \mathrm{FREST} \qquad (\mathrm{kg\ N\ ha^{-1}\ yr^{-1}})$$

$$\mathrm{DMGSUM} = \sum_{i=0}^{2} \sum_{j=0}^{2} \mathrm{DMGG(I,J)} * \mathrm{F(I,J)} + \mathrm{DMGRST} * \mathrm{FREST} \qquad (\mathrm{kg\ ha^{-1}\ yr^{-1}})$$

$$\mathrm{DMTSUM} = \sum_{i=0}^{2} \sum_{j=0}^{2} \mathrm{DMTT(I,J)} * \mathrm{F(I,J)} + \mathrm{DMTRST} * \mathrm{FREST} \qquad (\mathrm{kg\ ha^{-1}\ yr^{-1}})$$

Next, the average additional N uptake and herbage production per ha due to urine are calculated, by comparing the values with and without grazing. The utilization efficiency of urine N (FNUUP) is the fraction of the N excreted that is taken up in addition to the fertilizer N.

NUPE = NUPSUM - NUPDMT (kg N ha^{-1} yr^{-1})
DME = DMTSUM - DMT (kg ha^{-1} yr^{-1})
FNUUP = NUPE / NUS (-)

The stocking rate has been adapted to net herbage production. However, grazing results in additional herbage production, creating a forage surplus, and a higher N content of the herbage, which in turn results in an increased N excretion with urine. Therefore, all calculations as described in this section, are repeated on the basis of the herbage production (DMGSUM) and N uptake (NUPGSM) calculated under grazing. The values of the relevant variables are reset to the appropriate values.

DMG = DMGSUM (kg ha^{-1} yr^{-1})
NUPDMG = NUPGSM (kg N ha^{-1} yr^{-1})
NUPDMC = NUPCSM (kg N ha^{-1} yr^{-1})

The second iteration again results in a herbage surplus and a higher N uptake. Both herbage production and N uptake move towards an equilibrium. However, after the second iteration the main effects of grazing have been taken into account and more iterations do not have much effect, especially when considering the purpose of the study and the accuracy of the input data of GRASMOD. Strictly speaking, the influence of grazing should be calculated for each harvesting period separately. However, the time resolution of the model is one year and the second iteration is executed to approach the average influence of grazing.

4.5 Nitrogen losses to the environment

Nitrogen not taken up by herbage or accumulated in the soil is lost from the production system by volatilization of ammonia or leaching or denitrification of nitrate. The production system considered in GRASMOD includes the rooted zone of the soil. Therefore, N accumulating in the rooted soil zone is not considered a loss. It may become available again at a later stage and can then either be taken up by plants or leached or denitrified as yet.

4.5.1 Nitrate leaching and denitrification

The magnitude of nitrate leaching depends on the amount of nitrate present in the soil, soil type, depth of the groundwater table, interactions with the growing crop, grassland utilization method and weather conditions (Jarvis et al., 1987; Van der Meer & Meeuwissen, 1989). Leaching takes place when rainfall exceeds water loss by evapotranspiration and thus, in the Netherlands, occurs mainly in the winter period. However, during intensive showers in summer some nitrate may also be transported below the rooted zone.
From results of field experiments, Van der Meer and Meeuwissen (1989) derived a relation between fertilizer application and nitrate leaching for cut grass on well-drained sandy soils in the Netherlands (Figure 16).
Under anaerobic conditions and in the presence of oxidizable organic matter and nitrate, N may also be lost by denitrification, i.e. the reduction of nitrate to N_2. The last step in the denitrification process is the conversion of N_2O to N_2. However, under certain conditions, part of the N_2O is not reduced any further, but escapes directly to the atmosphere. The ratio N_2O/N_2 during the denitrification process is highly variable.

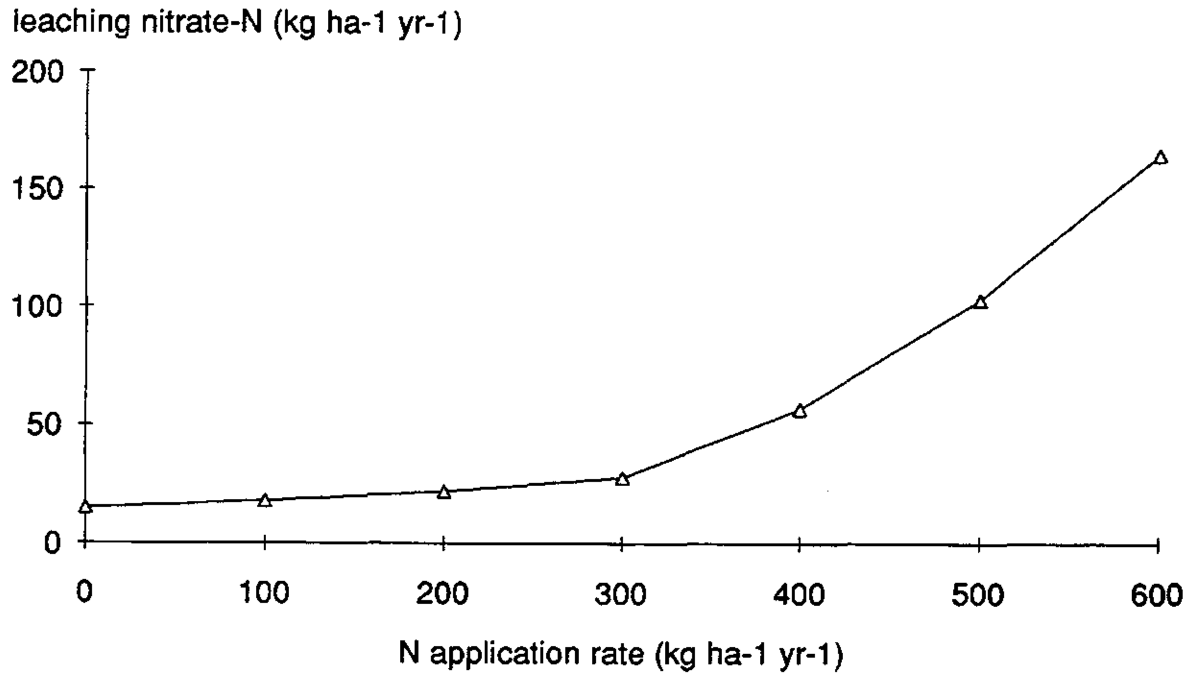

Figure 16. **Nitrate leaching losses from cut swards on sandy soils with a deep groundwater table, as influenced by N application rate (Van der Meer & Meeuwissen, 1989).**

Production of both gasses leads to N losses from the production system, but only N2O acts as a greenhouse gass and is therefore harmfull to the environment. Water has no direct effect on denitrification, but because of its effect on the oxygen status of the soil, soil moisture content has a large indirect effect (Corré & de Klein, 1990).
For soils with a higher groundwater table than the one represented in Figure 16 nitrate leaching should be corrected for denitrification. Several authors (Steenvoorden, 1988; Boumans et al., 1989) derived correction factors for nitrate leaching in dependence of depth of the groundwater table. In GRASMOD the groundwater table is not considered. The total amount of N lost from the soil profile, is derived from Figure 16, and is not distributed between leaching an denitrification.
In the model nitrate loss is not affected by harvesting regime, because at a given N application rate, annual uptake is similar and thus also the amount of N subject to leaching. The EC norm for drinking water is based on the nitrate concentration and is 50 mg nitrate per liter 2 m below the water table. However, in GRASMOD only the total amount of N in kg ha^{-1} yr^{-1} transported below the rooted zone is considered and not the nitrate concentration in the groundwater.
Nitrate loss in the non-fertilized situation (NO3OM) is estimated at 15 N kg ha^{-1} yr^{-1} (Van der Meer & Meeuwissen, 1989). This nitrate originates from decomposition of soil organic matter and atmospheric deposition, that is not taken up by herbage. Nitrate loss from fertilizers (NO3FER) is derived from Figure 16, defined in the model as an array (TNO3). The function AFGEN is used to interpolate between consecutive values of NFERT. For N application rates above 600 kg ha^{-1} yr^{-1}, Figure 16 is extrapolated assuming that 70% of the additional N is lost (Van der Meer & Meeuwissen, 1989). If the application rate exceeds 1000 kg ha^{-1} yr^{-1} is assumed 100% of the additional N is lost. Total nitrate loss is calculated as the sum of the nitrate loss from fertilizers and from organic matter and atmospheric deposition.

NO3FER = AFGEN(TNO3,16,NFERT) (kg N ha^{-1} yr^{-1})
NO3T = NO3FER + NO3OM (kg N ha^{-1} yr^{-1})

Nitrate loss from grazed swards is calculated for each of the ten field parts separately (NO3(I,J) and NO3RST). The N load in the various field parts after the second iteration is known and from Figure 16 the associated nitrate loss is derived. Next, the weighted total nitrate loss from urine (NO3SUM) and the additonal nitrate loss due to grazing (NO3E) are calculated.

$$\mathrm{NO3(I,J)} = \mathrm{AFGEN(TNO3,16,NM(I,J))} + \mathrm{NO3OM} \qquad \text{(kg ha}^{-1}\text{ yr}^{-1}$$

$$\mathrm{NO3SUM} = \sum_{i=0}^{2} \sum_{j=0}^{2} \mathrm{NO3(I,J)} * \mathrm{F(I,J)} + \mathrm{NO3RST} * \mathrm{FREST} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

$$\mathrm{NO3E} = \mathrm{NO3SUM} - \mathrm{NO3FER} - \mathrm{NO3OM} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

4.5.2 Ammonia volatilization

Ammonia volatilization originates from decaying herbage (NH3DG), slurry application and, if grazing is involved, from faeces and urine. The grazing and harvesting losses are considered to be decaying in the field and it is assumed that 3% of its N content (FNH3DG) volatilizes as ammonia (Vertregt & Rutgers, 1988). Slurry application is not considered in GRASMOD, so neither is the associated ammonia volatilization.
Some experimental results (Vertregt & Rutgers, 1988; Bussink, 1989; Jarvis et al., 1987) indicate that ammonia volatilization from urine voided at pasture depends on its N concentration. However, is has not yet been possible to quantify this relation, because of scarcity of data. In the first instance, ammonia volatilization is set at 13% of the N excreted in urine (FNH3U), independent of the concentration (Vertregt & Rutgers, 1988). Ammonia volatilization from faeces (FNH3F) also amounts to 13% of the N excreted (Vertregt & Rutgers, 1988). Volatilization does not have to be calculated for each of the field parts separatly, because, according to the assumptions described above, it is linearly related to the total N excreted with urine and faeces. Next, the total NH_3 losses are calculated.

$$\mathrm{NGHLOS} = \mathrm{NUPDMG} * \mathrm{GHLDMG} + \mathrm{NUPDMC} * \mathrm{HLDMC} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

$$\mathrm{NH3DG} = \mathrm{FNH3DG} * \mathrm{NGHLOS} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

$$\mathrm{NH3US} = \mathrm{FNH3U} * \mathrm{NUS} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

$$\mathrm{NH3FS} = \mathrm{FNH3F} * \mathrm{NFS} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

$$\mathrm{NH3T} = \mathrm{NH3DG} + \mathrm{NH3US} + \mathrm{NH3FS} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

Volatilization from inorganic fertilizers is very low and has therefore been set to zero. Vertegt and Rutgers (1988) concluded from in their N balance studies with urine that after 10 days, on average 27% of the N in urine was not accounted for, which possibly may be explained by chemo-denitrification. In the model, this is accounted for as a balance loss (NBLU).

$$\mathrm{NBLU} = \mathrm{FNBLU} * \mathrm{NUS} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

4.6 Nitrogen balance

So far, part of the N is not accounted for in the model. To gain insight in the consequences of combining all the previously described processes, for which information has been collected from various sources, this N not accounted for has been quantified.
The N losses due to feeding in the stable are added to the slurry:

$$\mathrm{NSLUR} = \mathrm{NSLUR} + \mathrm{NFLOS} \qquad \text{(kg N ha}^{-1}\text{ yr}^{-1}\text{)}$$

The other N 'losses' originate from decomposition of organic matter and deposition (LNOMDP), the fertilizer application (LNFERT), grazing (LNG), urine (LNUS) and faeces (LNFS). The 'losses' simply follow from subtracting all N accounted for in the various processes from the total N input.

LNOMDP = NOM + NDP - BASNUP - NO3OM	(kg N ha^{-1} yr^{-1})
LNFERT = NFERT - NUPFER - NO3FER	(kg N ha^{-1} yr^{-1})
LNG = NGFLOS - NH3DG	(kg N ha^{-1} yr^{-1})
LNUS = NUS - NH3US - NO3E - NUPE - NBLU	(kg N ha^{-1} yr^{-1})
LNFS = NFS - NH3FS	(kg N ha^{-1} yr^{-1})

For both the inorganic and the organic soil N a balance is constructed by listing all inputs and outputs (INORNI, INORNO, ORNI, ORNO). If no other loss processes than described in the preceding sections occur, the N not accounted for contributes either to the soil organic or inorganic N pool. It has been assumed that on an annual basis N only accumulates in the soil in organic form. Hence, all N added to the inorganic N pool and is not taken up, volatilized, leached or denitrified, is considered to be immobilized (NIMM). Thus, immobilization as calculated in GRASMOD is the overall result of other processes going on in the system. Inputs into the soil organic N pool (ORNI) are N 'losses' originating from faeces, grazing and harvesting losses and the immobilized N. The difference between inputs and outputs of the soil organic N is the surplus of N entering the system (NSURPL). If the surplus is positive N is accumulating in the soil, if it is negative soil N is slowly being exhausted.

INORNI = NOM + NDP + NFERT + (NUS - NH3US -NBLU)	(kg N ha^{-1} yr^{-1})
INORNO = NUPDMT + NO3T +NIMM	(kg N ha^{-1} yr^{-1})
ORNI = LNFS + LNG + NIMM	(kg N ha^{-1} yr^{-1})
ORNO = NOM + NSURPL	(kg N ha^{-1} yr^{-1})

N 'losses' originating from fertilizer application, urine, deposition and mineralisation, in first instance, contribute to soil inorganic N.

NIMM = LNFERT + LNUS + LNOMDP	(kg N ha^{-1} yr^{-1})

On the basis of all calculations executed in GRASMOD, an overall N balance sheet of the selected production systems, including the dairy stock, is calculated.

4.7 Model output

Two types of output are generated by GRASMOD, one intended as input for the LP MODEL, which is always generated (GRAS.DAT), and a more elaborate one, generated on request. The latter one consists of various files. GRAS.DOC provides the input data, the results per ha grassland, an N balance for grassland, for the dairy stock and for the soil, an overall input/output table and, if grazing took place, details on the ten field parts. DIET.DOC provides the formulated feed ration for the dairy cows. FEED.DOC gives the feeding value of the herbage for the two summer periods separately.
In GRAS.DAT no comments are included, because the file only serves as an input for the LPP. If additional information is required, it should be extracted from GRAS.DOC.

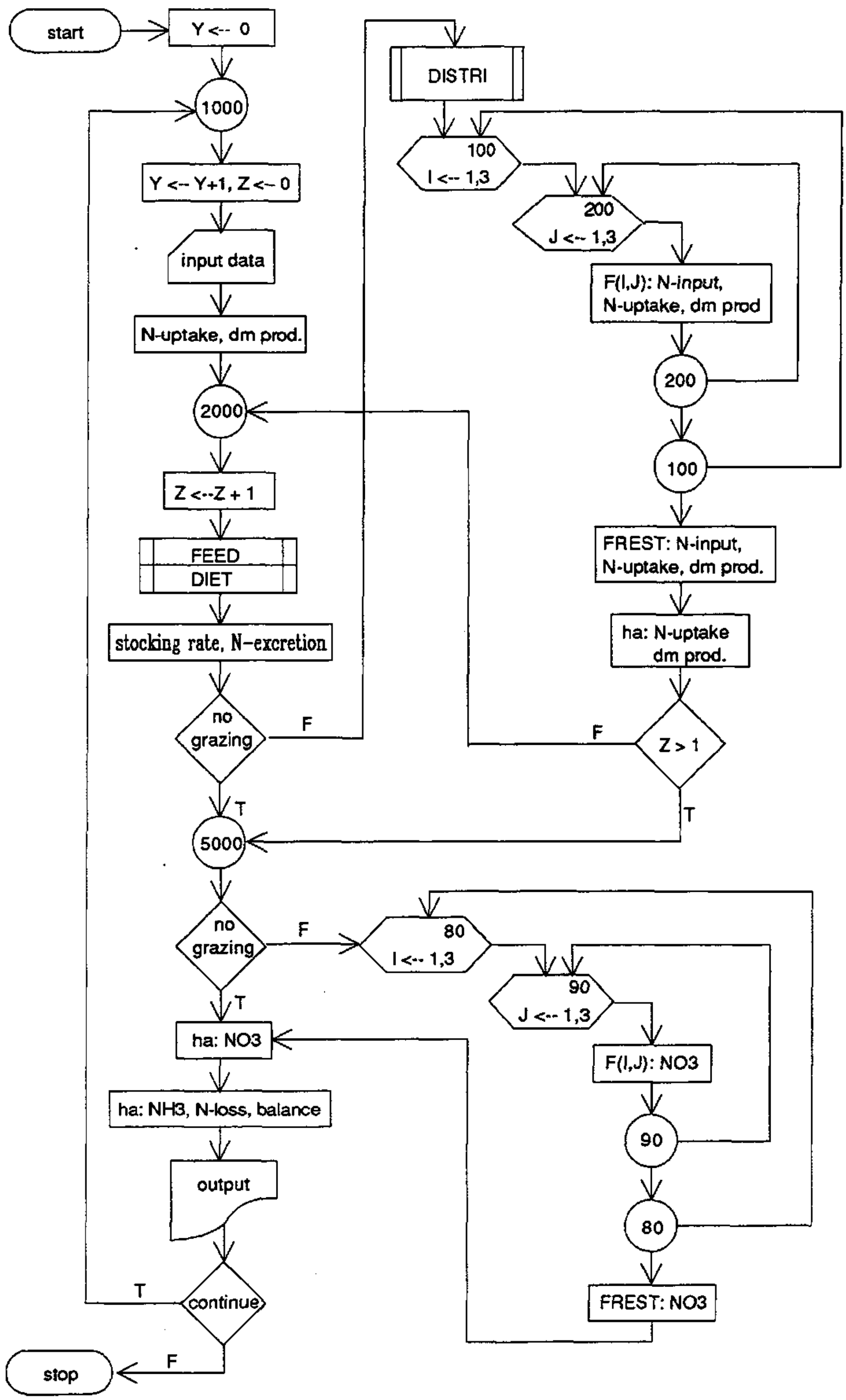

Figure 17. Overall structure of GRASMOD.

4.8 Flow chart of model execution

Figure 17 illustrates the overall structure of GRASMOD. The first column represents the sequence of calculations for zero grazing.
If a grassland utilization method including grazing, is selected, the influence of urine and faeces has to be taken into account. The additional calculations required for those patches are represented in the loop at the right hand side of the first colom.
The model can be run for one specific situation, but also for several situations successively without leaving the model. The variable Y tracks the number of iterations and its initial value is set to zero.
The label 1000 indicates the start of an iteration and thus the counter Y is set to the value Y+1. Next, the input data, comprising grassland utilization method, amount of N fertilizer applied, cutting percentage, milk production per cow per year and concentrate input, need to be specified. For each iteration those data can be inserted manually, but they can also be read from the file GRAS.INP, which is especially convenient for a large number of consecutive iterations.
From the input data N uptake by the herbage, gross and net herbage production are calculated. The nutritive value of the herbage is calculated in the subroutine FEED and the feed ration of the cows during the grazing season is calculated in the subroutine DIET. From the results the stocking rate and N excretion by the cows are derived. Next, two routes can be followed, the choice depending on grassland utilization system.
If the grassland utilization method does not include grazing, which means that zero grazing is applied or that all grass is conserved for winter feeding, the calculations continue from label 5000. Nitrate losses from the rooted zone, ammonia volatilization, other N losses and the N balance are calculated. The results are written to output files.
Next, the user can chose whether he wants to continue with another iteration. If so, the calculations restart at label 1000 and the counter Y is set to Y+1. If not, the program proceeds to the end of the model.
If the grassland utilization method includes grazing, the calculations for urine and faeces patches are involved and instead of proceeding to label 5000, the subroutine DISTRI is called. In DISTRI the area covered with faeces and urine is calculated from the stocking rate. The field is sub-divided in ten parts. Urine application is represented by I, faeces application by J and the value of both I and J ranges from 1 to 3. If I/J equals 1 no urine/faeces are applied, if I/J equals 2 the area is covered once with urine/faeces and if I/J equals 3 the area is covered twice. F(I,J) represents the fraction of the area covered I times with urine and J times with faeces. The remainder of the area, FREST, is covered more than twice with urine or faeces. The N-load is expressed in kg ha^{-1} for each of the field parts. The additional N from urine and/or faeces is added to the applied fertilizer N to calculate total N supply to the herbage. For each of the nine field parts F(I,J), N input, N uptake and dry matter production are calculated in a DO loop. The calculation procedure is identical to that described before for the zero grazing system. The calculations are then repeated for FREST. The results per ha grassland are calculated as the average of all ten field parts weighted according to their relative areas.
The average N-content of the herbage, calculated in this loop, is higher than initially obtained from the input data, hence more N is ingested by the animals. That additional N is

excreted in faeces and urine, as N incorporation in milk and meat do not change. Consequently, N inputs in urine and faeces patches and dry matter production are also higher and the loop has to be repeated with the new results. Here one enters a loop, that moves towards an equilibrium. In the model this loop is broken when Z reaches the value 2, i.e. after two iterations (Section 4.4.4). The procedure then continues from label 5000. If grazing is involved, nitrate losses from the rooted zone are calculated for each of the ten field parts separately in a DO loop. Next the weighted average leaching losses per ha are calculated and the procedure is terminated in the same way as described for the zero grazing systems.

5 Quantification of the potassium flow on grassland

In GRASMOD, quantification of the potassium flows in the dairy farming system is linked to the N flows, so the calculations on K follow after those on N. Many calculations run parallel to those described in the previous chapter. Hence, they will not be treated in the same detail again.

5.1 The optimum potassium content

The optimum K content in both freshly consumed and conserved herbage (DCKDMG, DCKDMC) is calculated, using the relation described in Section 3.4:

DCKDMG = (7.46 * 6.25 * CNDMG + 1.582) / 100 (-)

DCKDMC = (7.46 * 6.25 * CNDMC + 1.582) / 100 (-)

The optimum K content will be compared lateron with the actual K uptake to assess whether the K supply in the selected production system has been sufficient.

5.2 Potassium application and uptake by herbage

K taken up by herbage originates from soil reserves, deposition and fertilizer application. K uptake from soil reserves (KUPSL) is estimated at 175 kg ha^{-1} yr^{-1} (Section 3.3). K deposition (KDP) is estimated at 9 kg ha^{-1} yr^{-1} (Van Beek, 1987). K uptake from deposition (KUPKDP) is calculated taking into account that only part is deposited during the growing season (MAXDP) and that the K recovery at a low K availability is 0.7 (KRECI).

KUPSL = 175 (kg K ha^{-1} yr^{-1})

KUPKDP = MAXDP * KRECI * KDP (kg K ha^{-1} yr^{-1})

K fertilizer application (KFERT) is calculated according to the advice given by the Dutch extension service, which differs for the various grassland utilization methods (Section 3.3). In the following equations, the first line represents K application to the first cut and the second line to the remainder of the cuts. The factor 0.83 is used to convert K_2O into K.

Zero grazing:

- cutting percentage below 100%:

KFERT = (140 * 0.01*MP + 70 * (1 - 0.01*MP)
+ 100 *(DMG - (1-0.01*MP)*C2/C2)
* 0.83 (kg K ha^{-1} yr^{-1})

- cutting percentage above 100%:

KFERT = (140

+ 70 * (DMG + DMC - C3) / C2
* 0.83 (kg K ha^{-1} yr^{-1})

Daytime grazing: AK = 90.
Day-and-night grazing: AK = 0.

- cutting percentage below 100%:

KFERT = (140 * 0.01*MP + 70 * (1 - 0.01*MP)
+ AK)
* 0.83 (kg K ha^{-1} yr^{-1})

- cutting percentage above 100%:

KFERT = (140
+ 70 * (DMC - C3)/C3 + AK)
* 0.83 (kg K ha^{-1} yr^{-1})

If all herbage is grazed, only for the first cut some fertilizer K is applied, because most of the K ingested by the cowsis recirculted with faeces and urine. Thus, the distribution of K depends to a large extent on the distribution of K with faeces and urine. This distribution is very heterogeneous and large differences in the K status of the soil and the herbage will occur

The K recovery of fertilizers is estimated at 0.7 for application rates upto 400 kg ha^{-1} yr^{-1} (Van de Ven, 1990) and at 0.25 for every additional kg. These data described by in array (TKUPF) and the AFGEN function is used for interpolation between the data. Total K uptake (KUPDMT) is calculated by adding the K uptake from all three sources. However, the maximum K/N ratio in herbage has been set at 1.4 (Section 3.3) and thus the K uptake is limited by the N uptake. It has been assumed that K uptake from fertilizers is reduced if the total uptake would exceed the maximum.

KUPFER = AFGEN(TKUPF,6,KFERT) (kg K ha^{-1} yr^{-1})
KUPMDT = KUPSL + KUPKDP + KUPFER (kg K ha^{-1} yr^{-1})
if KUPDMT > 1.4 * NUPDMT: KUPDMT = 1.4 * NUPDMT (kg K ha^{-1} yr^{-1})
KUPFER = KUPDMT - KUPSL - KUPKDP

The distribution of K over freshly consumed and conserved herbage is proportional to the distribution of N. Next, the actual K content is calculated.

KUPDMG = NUPDMG/NUPDMT * KUPDMT (kg K ha^{-1} yr^{-1})
KUPDMC = NUPDMC/NUPDMT * KUPDMT (kg K ha^{-1} yr^{-1})
CKDMG = KUPDMG / DMG (-)
CKDMC = KUPDMC / DMC (-)

5.3 Potassium intake and excretion by dairy cattle during summer

The K content of concentrates (CKCON) is estimated at 1.5% (Biewinga et al., 1987) and of silage maize (CKM) at 1.7% (Schröder, pers. comm). Stocking rate and the ration of the dairy cattle are calculated as described in Section 4.3, so next, total K intake is calculated (KIDC).

KIC = RGD * COIDC * CKCON (kg K ha^{-1} yr^{-1})
KIM = RGD * MAIDC * CKM (kg K ha^{-1} yr^{-1})
KIDC = CKDMG * DMGDC + KIC + KIM (kg K ha^{-1} yr^{-1})

The K consumed by the animals is incorporated in milk and meat (KPS) or excreted in faeces and urine (KEXDC). The K content of milk is 0.16% and of meat 0.20% (Coppoolse et al., 1990). It is assumed that 90% of the K is excreted in urine (KTU) and only 10% in faeces (KFT). The amounts of K voided at pasture and collected in slurry are calculated in a similar way as is done for N.

KPS = SR * (0.535 * MILK * 0.0015 + 180/365 * MEAT * 0.002) (kg K ha^{-1} yr^{-1})
KEXDC = KIDC - KPS (kg K ha^{-1} yr^{-1})
KTU = KEXDC * 0.9 (kg K ha^{-1} yr^{-1})
KFT = KEXDC - KTU (kg K ha^{-1} yr^{-1})
KUEXS = KTU / (12 * RGD) (kg K ha^{-1} yr^{-1})
KFEXS = KFT / (12 * RGD) (kg K ha^{-1} yr^{-1})
KSU = KTU * GF * MF (kg K ha^{-1} yr^{-1})
KFS = KFT * GF * MF (kg K ha^{-1} yr^{-1})
KSLUR = KTU - KSU + KFT - KFS (kg K ha^{-1} yr^{-1})

5.4 Influence of grazing

If grazing is involved, the K load by urine and faeces (KU(I,J), KF(I,J)) is calculated in kg per ha urine and faeces patch. For K it has also been assumed that seasonal effects reduce the the amount of urine and faeces K, potentially available for plant uptake, by 65%. K in faeces is inorganic form. Therefore, it has been assumed that K in faeces, unlike N in faeces, is taken up by the herbage until the maximum K/N ratio of 1.4 is attained. K does not increase herbage production, as that is limited by the N supply. K uptake is calculated for each of the ten field parts in the same way as for the area not influenced by excreta, using the total N load KM(I,J) as the K application rate. The distribution of K over herbage grazed and conserved is determined by their respective parts in the total dry matter production. The desired and the actual K contents of both herbage grazed and conserved are calculated.

KU(I,J) = KUEXS / AREAU * (I - 1) (kg K ha^{-1} yr^{-1})
KF(I,J) = KFEXS / AREAF * (J - 1) (kg K ha^{-1} yr^{-1})

KM(I,J) = KFERT + (KU(I,J) + KF(I,J)) * FUPSEA (kg K ha^{-1} yr^{-1})

To arrive at the average K uptake per ha of land (KUPSUM), the results are weighted according ot their share in the surface area.

$$KUPSUM = \sum_{I=1}^{3} \sum_{J=1}^{3} KUP(I,J) * F(I,J) + KUPRST * FREST \quad (\text{kg K ha}^{-1}\ \text{yr}^{-1})$$

The average K uptake for grazed and for conserved herbage are calculted in the same way. Next, the average additional K uptake per ha due to urine and faeces is calculated, by comparing the uptake with and without grazing. The utilization efficiency of urine and faeces K is the fraction of the K excreted that is taken up in addition to fertilizer K.

KUPE = KUPSUM - KUPDMT (kg K ha^{-1} yr^{-1})
FKUFP = KUPE / (KSU + KFT) (-)

For calculations in the second iteration the same procedure as for N is followed (Section 4.4.4).

5.5 Potassium balance

For K a balance sheet has been drawn based on the information and assumptions described above. K not accounted for is calculated using equations similar to those used for N.
K losses originating from:

- grazing/harvesting and feeding losses:
  KGHLOS = KUPDMG * GHLDMG + KUPDMC * HLDMC (kg K ha^{-1} yr^{-1})
  KFLOS = KUPDMG * (1-GHLDMG) * FLDMG
  + KUPDMC * (1-HLDMC) * FLDMC (kg K ha^{-1} yr^{-1})
  LKGF = KGHLOS + KFLOS (kg K ha^{-1} yr^{-1})
- fertilizer:
  LKFERT = KFERT - KUPFER (kg K ha^{-1} yr^{-1})
- deposition:
  LKDP = KDP - KUPKDP (kg K ha^{-1} yr^{-1})
- faeces and urine
  LKUFS = KSU + KFS - KUPE (kg K ha^{-1} yr^{-1})
- total K not accounted for:
  KLOSS = LKFERT + LKDP + LKGF + LKUFS (kg K ha^{-1} yr^{-1})

K not accounted for is added to the soil reserves. The K surplus (KSURPL) is calculated as the difference between K not accounted for and the annual herbage uptake from the soil reserves. If the surplus is negative the soil is being depleted of K, if it is positive K is accumulating in the soil. On sandy soils it is likely that surplus K leaches during the winter period, as the adsorption capacity of the soil is limited.

KSURPL = KLOSS - KUPSL (kg K ha^{-1} yr^{-1})

Assuming no other loss and input processes occur than those described above, the surplus calculated for the soil balance sheet represents the K entering, or in the case the surplus is negative, leaving the system. In the output file an overall K balance sheet of the selected production system is given.

6 Some examples of model results

The results of GRASMOD are presented in several tables, GRAS.DOC, DIET.DOC and FEED.DOC. The tables are self-explanatory and can be read as such. For each of the four grassland utilization systems one set of results is given in the tables. Run 1 applies to zero grazing without supply of maize silage, run 2 to zero grazing including the supply of maize silage, run 3 to day-and-night grazing and run for to day grazing only. The fertilizer application rate is set to 250 kg ha^{-1} yr^{-1}, the cutting percentage at 150%, the milk production per cow to 6 500 kg and the low protein concentrates are selected.
In Table 8 the overall results are given for the four runs. The figures are averages per ha over the whole summer period.

Table 8. Overall results of GRASMOD for four runs. 1: zero grazing, no supply of maize silage; 2: zero grazing, supply of maize silage; 3: day and night grazing, no supply of maize silage; 4: day grazing only, supply of maize silge. All figures are in kg ha^{-1} yr^{-1} for 1 ha grassland, unless stated otherwise.

results	run 1/2		run3		run 4	
	fresh	silage	fresh	silage	fresh	silage
dm gross	8377	4500	7570	4500	7505	4500
dm nett	7635	4050	6056	4050	6456	4050
N uptake	238	117	256	123	248	121
N content (g kg^{-1})	2.84	2.61	3.38	2.73	3.31	2.68
K uptake	291	144	222	107	246	119
K content	3.48	3.20	2.94	2.37	3.28	2.65
averages per ha grassland						
NO3 loss	25		43		32	
volatilization	1		20		12	
utilization urine N (%)	0		23.7		25.4	
utilization urine + faeces K (%)	0		34.4		31.1	
N application	250		250		250	
P application	366		145		220	
K application	57		24		37	
stocking rate (cows ha^{-1})	3.2/4.3		2.1		3.4	
milk production	10985/14379		7441		11661	
meat production	96/125		65		101	

For zero grazing with and without feeding of maize silage, the results per ha grassland only differ with respect to stocking rate and total production. As the cows are never on the pasture, the stocking rate does not influence the pasture. The stocking rate per ha grassland increases, and thus production also, if the cows are supplemented with maize silage. Zero grazing without supply of maize silage should be compared to day and night grazing and zero grazing with supply of maize silage to day grazing only. This comparison shows that in grazing systems the production is lower than in no-grazing systems. Volatilization and nitrate losse are much higher at the same N application rate. The N content of silage, produced in grazing systems is a somewhat higher due to additional N application with urine. However, the difference is very small.
It should be noted that these figures only apply to dairy cows during the summer season. At farm level also young stock and the winter period should be taken into account. The adaptation of GRASMOD to young stock is described in a separate report (Boons, 1992) and the winter period is taken into account in the LP-model.
In Appendix 3 the complete output of the model is given for all four situations. This comprises:

- the average results for one ha grassland;
- the average diet per cow;
- N balance sheet for grassland;
- N balance sheet for the soil, both for organic and inorganic N;
- N balance sheet for dairy cows;
- N input/output table;
- K balance sheet for grassland;
- K balance sheet for the soil;
- K balance sheet for dairy cows;
- K input/output table;
- details of urine and faeces patches.

In Table 9 the feeding value of the herbage is specified. For conserved herbage E is equal to 1, for herbage fed indoors E equals 2 and for herbage grazed E equals 3. This table shows that grazing also, altough very little, influences the feeding value of the herbage conserved.

Table 9. Output of the subroutine FEED.

FEED.OUT: feeding value of herbage						
	E	CN	MJ	DVE	OEB	FDCP
Y = 1	1	.026	5.918	50.	43.	.646
	2	.028	6.730	95.	20.	.742
Y = 2	1	.026	5.918	50.	43.	.646
	2	.028	6.730	95.	20.	.742
Y = 3	1	.027	5.933	51.	49.	.657
	3	.034	6.834	100.	50.	.778
Y = 4	1	.027	5.926	51.	47.	.653
	3	.033	6.822	99.	46.	.774

Table 10 shows the feed ration of the various systems for each of the two summer periods separately and the total feed intake summed over the whole summer period.

Table 10. Output of the subroutine DIET.

DIET.OUT: feed ration of dairy cows

Y = 1 (zero grazing, no supply of maize silage)

P	ENRT	DMIMAX	RM	CONRDC	RCON	GIDC	MAIDC	COIDC	C1	C2	C3	C4	DVES	OEBIT	DSIDC	SW
1	113.52	14.3	.0	2.80	.8	13.5	.0	2.8	2.8	.0	.0	.0	135.	214.	16.3	.46
2	91.96	13.2	.0	.96	.3	12.9	.0	1.0	1.0	.0	.0	.0	315.	239.	13.9	.51

GIDCS = 2417.
MAIDCS = 0.
COIDCS = 319.
CNCON = .014
FDCPO = .65

Y = 2 (zero grazing, supply of maize silage)

P	ENRT	DMIMAX	RM	CONRDC	RCON	GIDC	MAIDC	COIDC	C1	C2	C3	C4	DVES	OEBIT	DSIDC	SW
1	113.52	14.3	.7	1.80	.5	10.5	4.5	1.8	1.8	.0	.0	.0	0.	102.	16.8	.52
2	91.96	13.2	.7	.00	.0	9.7	4.5	.0	.0	.0	.0	.0	164.	123.	14.2	.58

GIDCS = 1847.
MAIDCS = 828.
COIDCS = 139.
CNCON = .014
FDCPO = .65

Y = 3 (day and night grazing, no supply of maize silage)

P	ENRT	DMIMAX	RM	CONRDC	RCON	GIDC	MAIDC	COIDC	C1	C2	C3	C4	DVES	OEBIT	DSIDC	SW
1	119.25	16.6	.0	.60	.2	16.4	.0	.6	.6	.0	.0	.0	360.	809.	17.0	.53
2	97.69	15.3	.0	.00	.0	14.6	.0	.0	.0	.0	.0	.0	494.	731.	14.6	.55

GIDCS = 2830.
MAIDCS = 0.
COIDCS = 46.
CNCON = .014
FDCPO = .65

Y = 4 (day grazing only, supply of maize silage)

P	ENRT	DMIMAX	RM	CONRDC	RCON	GIDC	MAIDC	COIDC	C1	C2	C3	C4	DVES	OEBIT	DSIDC	SW
1	118.35	14.9	.8	2.13	.6	10.7	4.5	2.1	2.1	.0	.0	.0	90.	374.	17.3	.51
2	96.79	13.8	.8	.00	.0	10.3	4.5	.0	.0	.0	.0	.0	268.	400.	14.8	.58

GIDCS = 1925.
MAIDCS = 828.
COIDCS = 164.
CNCON = .014
FDCPO = .65

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APPENDIX 1 LIST OF ACRONYMS

code	description	unit
A	continuation indicator for next iteration	-
AK	K application for first harvest	kg ha^{-1}
AP	P application for first harvest	kg ha^{-1}
AREAF	area of a faeces patch	ha
AREAU	area influenced by one urination	ha
BASNUP	N uptake by herbage without N fertilizer application	kg ha^{-1} yr^{-1}
C	type of concentrate	-
C2	weigth of a cut for zero-grazing	kg ha^{-1}
C3	weight of a cut for conservation	kg ha^{-1}
CASH(E)	crude ash content of herbage at yield E	g kg^{-1}
CF(E)	crude fiber content of herbage at yield E	g kg^{-1}
CFAT	crude fat content of herbage	g kg^{-1}
CKC(I,J)	K content of herbage for conservation on F(I,J)	-
CKCON	K content of concentrates	-
CKCR	K content of herbage for conservation on FREST	-
CKDMC	average K content of pre-wilted silage	-
CKDMG	average K content of fresh herbage	-
CKG(I,J)	K content of herbage grazed on F(I,J)	-
CKGR	K content of herbage grazed on FREST	-
CKM	K content of maize silage	-
CN(C)	N content of concentrate type C	-
CNC(I,J)	N content of herbage for conservation on F(I,J)	-
CNCON	average N content of concentrates consumed in summer	-
CNCR	N content of herbage for conservation on FREST	-
CNDMC	average N content of pre-wilted silage	-
CNDMG	average N content of fresh herbage	-
CNG(I,J)	N content of herbage grazed on F(I,J)	-
CNGR	N content of herbage grazed on FREST	-
COIDC	average daily concentrate intake per cow during summer	kg cow^{-1} d^{-1}
COIDC(P)	daily concentrate intake per cow in period P	kg cow^{-1} d^{-1}
COIDCS	total concentrate intake per cow during summer	kg cow^{-1} $(184\ d)^{-1}$
CON1,CON2	intermediate variable to calculate concentrate intake	kg cow^{-1} d^{-1}
CON(P,C)	daily intake of concentrate type C in period P	kg cow^{-1} d^{-1}
CONCS	total concentrate intake during summer	kg ha^{-1} $(184\ d)^{-1}$
CONIDC(I)	daily concentrate intake per cow at replacement level I	kg cow^{-1} d^{-1}
CONRDC(P)	daily concentrate requirement per cow in period P at replacement level I=1	kg cow^{-1} d^{-1}
CP	crude protein content of herbage	g kg^{-1}
CP(C)	crude protein content of concentrate type C	g kg^{-1}

CPADG	crude protein content of artificially dried herbage	g kg^{-1}
CPCON	average crude protein content of concentrates consumed during summer	g kg^{-1}
CPI(P)	crude protein content of concentrates consumed during period P	g kg^{-1}
CT	types of concentrates to be used	-
D	number of full grazing days	d
DAY(E)	number of days after 1 April at which herbage at yield E is harvested	d
DCKC(I,J)	desired K content of herbage for conservation at F(I,J)	-
DCKCR	desired K content of herbage for conservation at FREST	-
DCKDMC	desired average K content of pre-wilted silage	-
DCKDMG	desired average K content of fresh herbage	-
DCKG(I,J)	desired K content of herbage grazed at F(I,J)	-
DCKGR	desired K content of herbage grazed at FREST	-
DCP	feeding standard crude protein of herbage	g kg^{-1}
DCPADG	feeding standard crude protein of artificially dried herbage	g kg^{-1}
DCPC	average feeding standard crude protein of concentrates consumed during summer	g kg^{-1}
DCPI(P)	feeding standard crude protein of concentrates consumed in period P	g kg^{-1}
DIET	subroutine calculating the feed ration	-
DIET.DOC	output file for results of the subroutine DIET	-
DISTRI	subroutine calculating the distribution of urine and faeces in the field	-
DM	dry matter content of pre-wilted silage	g kg^{-1}
DMC	gross amount of herbage used for conservation	kg ha^{-1} yr^{-1}
DMCDC	Net amount of pre-wilted silage	kg ha^{-1} yr^{-1}
DMCMAX	maximum herbage yield used for conservation at the specified N appliaction rate	kg ha^{-1} yr^{-1}
DMCMX(I,J)	maximum herbage yield used for conservation on F(I,J) at the specified N application rate	kg ha^{-1} yr^{-1}
DMCMXR	maximum herbage yield used for conservation on FREST at the specified N application rate	kg ha^{-1} yr^{-1}
DME	additional herbage production due to grazing	kg ha^{-1} yr^{-1}
DMG	gross herbage production for fresh consumption	kg ha^{-1} yr^{-1}
DMGDC	net herbage production for fresh consumption	kg ha^{-1} yr^{-1}
DMGG(I,J)	gross amount of herbage grazed on F(I,J)	kg ha^{-1} yr^{-1}
DMGMAX	maximum herbage yield used for fresh consumption at the specified N application rate	kg ha^{-1} yr^{-1}
DMGMX(I,J)	maximum amount of herbage grazed at the specified N application rate on F(I,J)	kg ha^{-1} yr^{-1}
DMGMXR	maximum amount of herbage grazed at the specified N application rate on FREST	kg ha^{-1} yr^{-1}
DMGRST	gross amount of herbage grazed on FREST	kg ha^{-1} yr^{-1}
DMGSUM	weighted average amount of herbage grazed on various field parts	kg ha^{-1} yr^{-1}

DMIMAX(P)	maximum daily herbage intake by dairy cows in period P, corrected for grassland utilization system G	kg cow^{-1} d^{-1}
DMT	total gross herbage yield	kg ha^{-1} yr^{-1}
DMTRST	gross herbage yield on FREST	kg ha^{-1} yr^{-1}
DMTSUM	weighted average herbage yield on various field parts	kg ha^{-1} yr^{-1}
DMTT(I,J)	gross herbage yield on F(I,J)	kg ha^{-1} yr^{-1}
DOM	digestibility of herbage organic matter	g kg^{-1}
DSIDC(P)	daily total dry matter intake by dairy cows in period P	kg cow^{-1} d^{-1}
DVBE	intestinally available undegraded protein content of herbage	g kg^{-1}
DVE	intestinally available protein content of herbage	g kg^{-1}
DVEC(C)	DVE content of concentrate type C	g kg^{-1}
DVEDMC	DVE content of pre-wilted silage	g kg^{-1}
DVEIC(P)	DVE intake required from concentrates in period P	kg cow^{-1} d^{-1}
DVEIF(P)	DVE intake with grass and maize silage	g cow^{-1} d^{-1}
DVEMAI	DVE content of maize silage	g kg^{-1}
DVERC(P)	daily DVE requirement for conception products in period P	g cow^{-1} d^{-1}
DVERG	daily DVE requirement for growth	g cow^{-1} d^{-1}
DVERM	daily DVE requirement for maintenance	g cow^{-1} d^{-1}
DVERP(P)	daily DVE requirement for milk production in period P	g cow^{-1} d^{-1}
DVERT(P)	total daily DVE requirement in period P	g cow^{-1} d^{-1}
DVES(P)	daily consumed DVE surplus in period P	g cow^{-1} d^{-1}
DVME	intestinally available microbial protein content of herbage	g kg^{-1}
DVMFE	intestinally available metabolic faecal protein content of herbage	g kg^{-1}
E	Index for dry matter yield of a cut	-
ENRC(P)	daily energy requirement for conception products in period P	MJ cow^{-1} d^{-1}
ENRF(M)	additional daily energy requirement due to energy shortages in other periods for milk production level M	MJ cow^{-1} d^{-1}
ENRG	daily energy requirement for growth	MJ cow^{-1} d^{-1}
ENRM	daily energy requirement for maintenance	MJ cow^{-1} d^{-1}
ENRP(P)	daily energy requirement for milk production in period P	MJ cow^{-1} d^{-1}
ENRS(G)	additional daily energy requirement for grassland utilization system G	MJ cow^{-1} d^{-1}
ENRT(P)	total daily energy requirement in period P	MJ cow^{-1} d^{-1}
F	vector of all F(I,J)	
F(I,J)	part of the field that receives Ix urine and Jx faeces during summer	-
FC(J)	part of the field covered Jx with faeces	-
FDCP	fraction digestible crude protein in herbage	-
FDCP(C)	fraction digestible crude protein of concentrate type C	-

FEED	subroutine calculating the feeding value of herbage	
FEED.DOC	output file for results of the subroutine FEED	
FKUFP	fraction of K taken up from urine and faeces	-
FLDMG	fraction of fresh herbage lost while feeding indoors	-
FNBLU	fraction of N in urine accounted for as a balance loss	-
FNH3F	fraction of N in faeces lost by volatilization	-
FNH3G	fraction of N in grazing losses lost by volatilization	-
FNH3U	fraction of N in urine lost by volatilization	-
FNUUP	fraction of N in urine taken up by herbage	-
FOS	fermentable organic matter content in herbage	g kg^{-1}
FP(E)	fermentation products of herbage at yield E	g kg^{-1}
FREST	fraction of the field covered more than 2x with urine or faeces	-
FSUM	sum of various field parts	-
FSYS(G)	factor for dry matter intake depending on grassland utilization system G	-
FUPSEA	fraction of urinary N available for plant uptake due to seasonal effects	-
G	index for grassland utilization systems	-
GE	gross energy content of herbage	kJ kg^{-1}
GF(G)	fraction of a grazing day the animals are outside for grassland utilization method G	-
GHLDMG(G)	fraction of herbage lost due to grazing and harversting for grassland utilization method G	-
GIDC	average daily herbage intake per cow	kg cow^{-1} d^{-1}
GIDC(P)	daily herbage intake per cow in period P	kg cow^{-1} d^{-1}
GIDCS	total herbage intake per during summer	kg cow^{-1} $(184\ d)^{-1}$
GRASN.DAT	file with the results from GRASMOD used in an Linear programming matrix	-
GRASN.DOC	output file containing detailed results of GRASMOD	-
GRASN.INP	input file containing user specified input data for GRASMOD	-
HARV(E)	factor accounting for the influence of the season for calculation of dom, based on the harvest date	g kg^{-1}
HLDMC	part of the herbage used for conservation lost due to harvesting	-
INORNI	inputs to the inorganic soil N pool	kg ha^{-1} yr^{-1}
INORNO	outputs from the inorganic soil N pool	kg ha^{-1} yr^{-1}
KDP	atmospheric K deposition	kg ha^{-1} yr^{-1}
KEXDC	K excreted in urine and faeces in summer	kg ha^{-1} $(184\ d)^{-1}$
KF(I,J))	K in faeces deposited on F(I,J)	kg ha^{-1} yr^{-1}
KFERT	K fertilizer application rate	kg ha^{-1} yr^{-1}
KFEXS	K excretion per defaecation	kg
KFLOS	K in feeding losses when feeding indoors in summer	kg ha^{-1} $(184\ d)^{-1}$
KFREST	K in faeces deposited on FREST	kg ha^{-1} yr^{-1}
KFS	K excreted with faeces during grazing	kg ha^{-1} yr^{-1}
KFSUM	weighted average K deposited with faeces on various field parts	kg ha^{-1} yr^{-1}
KFT	total K excreted with faeces in summer	kg ha^{-1} $(184\ d)^{-1}$
KGHLOS	K in grazing and harvesting losses	kg ha^{-1} yr^{-1}

KIC	K intake with concentrates in summer	kg ha^{-1} $(184\ d)^{-1}$
KIDC	total K intake in summer	kg ha^{-1} $(184\ d)^{-1}$
KIM	K intake with maize silage in summer	kg ha^{-1} $(184\ d)^{-1}$
KINPUT	total K inputs into the grassland system	kg ha^{-1} yr^{-1}
KLOSS	total K losses in the grassland system	kg ha^{-1} yr^{-1}
KM(I,J)	total K available to herbage on F(I,J)	kg ha^{-1} yr^{-1}
KMREST	total K available to herbage on FREST	kg ha^{-1} yr^{-1}
KOUTPT	total K outputs from the grassland system	kg ha^{-1} yr^{-1}
KPS	K incorporated in milk and meat in summer	kg ha^{-1} $(184\ d)^{-1}$
KRECI	K recovery at low fertilizer levels	-
KSLIN	K inputs into the soil K pool	kg ha^{-1} yr^{-1}
KSLOUT	K outputs from the soil K pool	kg ha^{-1} yr^{-1}
KSLUR	K in slurry produced in summer	kg ha^{-1} $(184\ d)^{-1}$
KSU	K deposited with urine in the field during grazing	kg ha^{-1} yr^{-1}
KSURPL	K surplus	kg ha^{-1} yr^{-1}
KTU	total K excreted with urine in summer	kg ha^{-1} $(184\ d)^{-1}$
KU(I,J)	K in urine deposited on F(I,J)	kg ha^{-1} yr^{-1}
KUEXS	K excretion per defaecation	kg
KUP(I,J)	K uptake by herbage on F(I,J)	kg ha^{-1} yr^{-1}
KUPC(I,J)	K uptake by herbage for conservation on F(I,J)	kg ha^{-1} yr^{-1}
KUPCR	K uptake by herbage for conservation on FREST	kg ha^{-1} yr^{-1}
KUPCSM	weighted K uptake by herbage for conservation on various field parts	kg ha^{-1} yr^{-1}
KUPDMC	average K uptake by herbage for conservation	kg ha^{-1} yr^{-1}
KUPDMG	average K uptake by herbage for fresh consumption	kg ha^{-1} yr^{-1}
KUPDMT	total K uptake by herbage	kg ha^{-1} yr^{-1}
KUPE	additional K uptake due urine and faeces deposition under grazing	kg ha^{-1} yr^{-1}
KUPFER	K uptake from fertilizer	kg ha^{-1} yr^{-1}
KUPG(I,J)	K uptake by herbage grazed on F(I,J)	kg ha^{-1} yr^{-1}
KUPGR	K uptake by herbage grazed on FREST	kg ha^{-1} yr^{-1}
KUPGSM	weighted K uptake by herbage grazed on various field parts	kg ha^{-1} yr^{-1}
KUPKDP	K uptake originating from atmospheric depostion	kg ha^{-1} yr^{-1}
KUPMAX	maximum K uptake	kg ha^{-1} yr^{-1}
KUPP	intermediate variable to calculate KUP(I,J) and KUPRST	kg ha^{-1} yr^{-1}
KUPRST	K uptake on FREST	kg ha^{-1} yr^{-1}
KUPSL	K uptake originating from the soil K pool	kg ha^{-1} yr^{-1}
KUPSUM	weighted average K uptake on various field parts	kg ha^{-1} yr^{-1}
KUREST	K in urine deposited on FREST	kg ha^{-1} yr^{-1}
KUSUM	weighted average K in urine on various field parts	kg ha^{-1} yr^{-1}
LKDP	K loss not accounted for originating from deposition	kg ha^{-1} yr^{-1}
LKFERT	K loss not accounted for originating from fertilizer application	kg ha^{-1} yr^{-1}
LKGF	K in grazing and feeding losses	kg ha^{-1} yr^{-1}
LKUFS	K loss not accounted for originating from urine and faeces deposition during grazing	kg ha^{-1} yr^{-1}
LNFERT	N loss not accounted for originating from fertilizer application	kg ha^{-1} yr^{-1}

LNFS	N loss not accounted for originating from faeces deposition during grazing	kg ha^{-1} yr^{-1}
LNG	N loss not accounted for in grazing and harvesting losses	kg ha^{-1} yr^{-1}
LNOMDP	N loss not accounted for originating from deposition and soil organic N	kg ha^{-1} yr^{-1}
LNUS	N loss not accounted for originating from urine deposition during grazing	kg ha^{-1} yr^{-1}
M	index for milk production level per cow	-
MAIDC	average daily maize silage intake per cow in summer	kg ha^{-1} $(184\ d)^{-1}$
MAIDC(G)	daily maize silage intake per cow under grassland utilization system G	kg ha^{-1} d^{-1}
MAIDCS	total maize silage intake per cow in summer	kg ha^{-1} $(184\ d)^{-1}$
MAISS	total maize silage intake in summer	kg ha^{-1} $(184\ d)^{-1}$
MAXDP	maximum fraction of N and K deposited available for plant uptake	-
MAXI(P)	maximum daily herbage intake per cow in period P	kg cow^{-1} d^{-1}
MAXNOM	maximum fraction of N mineralized available for plant uptake	-
MAXNUS	maximum fraction of N in urine available for plant uptake	-
ME	metabolic energy content of herbage	kJ kg^{-1}
MEAT	annual meat production per cow (growth + calf)	kg cow^{-1} yr^{-1}
MF	maximum fraction of a day available for grazing	-
MILK	annual milk production level per cow	kg cow^{-1} yr^{-1}
MILKD(P,M)	average daily milk production per cow in period P for milk production level M	kg cow^{-1} d^{-1}
MJ	NEL value of herbage	MJ kg^{-1}
MJADG	NEL value of artificially dried grass	MJ kg^{-1}
MJCON	NEL value of concentrates	MJ kg^{-1}
MJCONC(I)	additional NEL value in concentrates at substitution level I	MJ kg^{-1}
MJDMC	NEL value of pre-wilted herbage	MJ kg^{-1}
MJDMGP(1)	NEL value of fresh herbage in period P	MJ kg^{-1}
MJMAIS	NEL value of maize silage	MJ kg^{-1}
MP	cutting percentage	-
MUF	area expected to be covered 1x with faeces during the grazing season, without overlap	ha
MUU	area expected to be covered 1x with urine during the grazing season, without overlap	ha
N	number of defaecations and urinations during grazing	-
NBLU	N balance loss from urine in the field	kg ha^{-1} yr^{-1}
NCREST	inorganic N available for plant uptake	kg ha^{-1} yr^{-1}
NDP	N in atmospheric deposition	kg ha^{-1} yr^{-1}
NEXDC	N excreted in faeces and urine during grazing	kg ha^{-1} $(184\ d)^{-1}$
NF(I,J)	N deposited with faeces on F(I,J)	kg ha^{-1} yr^{-1}
NFERT	N fertilizer applicaton rate	kg ha^{-1} yr^{-1}
NFEXS	N excreted with 1 defaecation	kg
NFLOS	N in feeding losses when feeding indoors	kg ha^{-1} yr^{-1}

NFREST	N deposited with faeces on FREST	kg ha^{-1} yr^{-1}
NFS	N excreted with faeces during grazing	kg ha^{-1} yr^{-1}
NFSUM	weighted average N depostion on various field parts	kg ha^{-1} yr^{-1}
NFT	total N excreted with faeces during summer	kg ha^{-1} (184 d)$^{-1}$
NGHLOS	N in grazing and harvesting losses	kg ha^{-1} yr^{-1}
NH3DG	N volatilized from grazing and harvesting losses	kg ha^{-1} yr^{-1}
NH3FS	N volatilized from faeces deposited during grazing	kg ha^{-1} yr^{-1}
NH3T	total N volatilized in summer	kg ha^{-1} (184 d)$^{-1}$
NH3US	N volatilized from urine deposited during grazing	kg ha^{-1} yr^{-1}
NIC	N intake with concentrates	kg ha^{-1} (184 d)$^{-1}$
NIDC	total N intake by dairy cows in summer	kg ha^{-1} (184 d)1
NIM	N intake with maize silage	kg ha^{-1} (184 d)1
NIMM	N immobilization	kg ha^{-1} yr^{-1}
NINPUT	N input into the system	kg ha^{-1} yr^{-1}
NM(I,J)	inorganic N applied with urine subject to leaching and denitrification in F(I,J)	kg ha^{-1} yr^{-1}
NMC(I,J)	inorganic N available for plant uptake in F(I,J)	kg ha^{-1} yr^{-1}
NMF	name of field parts F(I,J) and FREST	-
NMGS	name of grassland utilization systems	-
NMU	inorganic N input from urine to the soil N pool	kg ha^{-1} yr^{-1}
NO3(I,J)	Nitrate loss from the rooted zone in F(I,J)	kg ha^{-1} yr^{-1}
NO3E	additonal nitrate loss from the rooted zone due to grazing	kg ha^{-1} yr^{-1}
NO3FER	nitrate loss from the rooted zone originating from fertilizer application	kg ha^{-1} yr^{-1}
NO3OM	nitrate loss from the rooted zone orginating from mineralized N	kg ha^{-1} yr^{-1}
NO3RST	nitrate loss from the rooted zone on FREST	kg ha^{-1} yr^{-1}
NO3SUM	weighted average nitrate loss from the rooted zone for various field parts	kg ha^{-1} yr^{-1}
NO3T	total nitrate loss from the rooted zone	kg ha^{-1} yr^{-1}
NOM	N originating from mineralization available for plant uptake	kg ha^{-1} yr^{-1}
NOUTPT	N output from the system via identified processess	kg ha^{-1} yr^{-1}
NPOOL	total N not accounted for via identified processe	kg ha^{-1} yr^{-1}
NPS	N incorporated in milk and meat in summer	kg ha^{-1} (184 d)$^{-1}$
NRECI	N recovery at low fertilizer levels	-
NREST	inorganic N applied with urine subject to leaching and denitrification in FREST	kg ha^{-1} yr^{-1}
NSLUR	N collected indoors in slurry	kg ha^{-1} yr^{-1}
NSURPL	N accumulation or depletion in the production system	kg ha^{-1} yr^{-1}
NU(I,J)	N deposited with urine on F(I,J)	kg ha^{-1} yr^{-1}
NUEXS	N excreted with one urination	kg ha^{-1} yr^{-1}
NUP(I,J)	N uptake on F(I,J)	kg ha^{-1} yr^{-1}
NUPC(I,J)	N uptake by herbage for conservation on F(I,J)	kg ha^{-1} yr^{-1}
NUPCR	N uptake by herbage for conservation on FREST	kg ha^{-1} yr^{-1}
NUPCSM	weighted average N uptake by herbage for conservation on various field parts	kg ha^{-1} yr^{-1}
NUPDMC	N uptake by herbage for conservation	kg ha^{-1} yr^{-1}

NUPDMG	N uptake by herbage for fresh consumption	kg ha^{-1} yr^{-1}
NUPDMT	total N uptake	kg ha^{-1} yr^{-1}
NUPE	additional N uptake due to grazing	kg ha^{-1} yr^{-1}
NUPFER	N uptake originating from fertilizer application	kg ha^{-1} yr^{-1}
NUPG(I,J)	N uptake by herbage grazed on F(I,J)	kg ha^{-1} yr^{-1}
NUPGR	N uptake by herbage grazed on FREST	kg ha^{-1} yr^{-1}
NUPGSM	weighted average N uptake by herbage grazed on various field parts	kg ha^{-1} yr^{-1}
NUPRST	N uptake on FREST	kg ha^{-1} yr^{-1}
NUPSUM	weighted average N uptake on various field parts	kg ha^{-1} yr^{-1}
NUREST	N deposited on FREST with urine	kg ha^{-1} yr^{-1}
NUS	N in urine excreted during grazing	kg ha^{-1} yr^{-1}
NUSUM	weighted average N in urine deposited on various field parts	kg ha^{-1} yr^{-1}
NUT	total N excreted with urine	kg ha^{-1} yr^{-1}
OEB	rumen degradable protein balance of herbage	g kg^{-1}
OEB1,OEB2, OEB3	intermediate variables to calculate OEB intake	g cow^{-1} d^{-1}
OEBC(C)	OEB content concentrate type C	g kg^{-1}
OEBDMC	OEB content of pre-wilted silage	g kg^{-1}
OEBDMG	OEB content of fresh herbage	g kg^{-1}
OEBI	total daily OEB intake	g cow^{-1} d^{-1}
OEBIC(P)	daily OEB intake with concentrates in period P	g cow^{-1} d^{-1}
OEBIF(P)	daily OEB intake with roughage in period P	g cow^{-1} d^{-1}
OEBIT(P)	total daily OEB intake in period P	g cow^{-1} d^{-1}
OEBMAI	OEB content of maize silage	g kg^{-1}
ORNI	N input into the soil organic N pool	kg ha^{-1} yr^{-1}
ORNO	N output from the soil organic N pool	kg ha^{-1} yr^{-1}
PBRE	percentage of undegraded dietary protein	-
PDCC	protein digestibility coefficient of concentrates	-
PDCG	protein digestibility coefficient of fresh herbage	-
PDCM	protein digestibility coefficient of maize silage	-
PDVBE	percentage of intestinally available undegraded protein	-
PERIOD(P)	number of days in period P	d
PFERT	P fertilizer application	kg ha^{-1} yr^{-1}
PRRE	percentage of residual crude protein	-
Q	ratio between metabolic and gross energy of herbage in per cent	-
R(P)	reduction factor for herbgae intake in period P, dpending on lactation stage	-
RC(I)	replacement factor of concentrates at replacement level I	-
RCON(P)	total amount of roughage replaced by concentrates in period P	kg
RGD	number of cow grazing days	d
RM(P)	repalcement factor of maize silage	-
SP	number of days in the summer period	d
SR	stocking rate	cows ha^{-1}
SRI	default stocking rate	cows ha^{-1}

SW(P)	structural value of the feed ration in period P	-
SWG)	structural value of herbage	-
SWM	structural value of maize silage	-
TEADG	tabulated energy values of artificially dried grass	MJ kg^{-1}
TKUPF	tabulated relation between K appication and K uptake	
TNDM1	tabulated relation between N uptake and dry matter production for harvesting at 1 700 ha^{-1}	
TNDM2	tabulated relation between N uptake and dry matter production for harvesting at 2 300 kg ha^{-1}	
TNDM3	tabulated relation between N uptake and dry matter production for harvesting at 3 000 kg ha^{-1}	
TNO3F	tabulated relation between N fertilizer rate and nitrate leaching	
TNUPF	tabulated relation between N applicaton and N uptake	
UR(I)	part of the field covered Ix with urine	-
VAR(C)	intermediate variable to calculated the type of concentrates consumed	kg
X	indicator for the type of output desired	-
XX	indicator for the type of input used	-
Y	counter for the number of iterations	
Z	counter for the internal loop	-

APPENDIX 2 LISTING OF GRASMOD

2.a Main program GRASMOD

```
*==================================================================*
* Program:      GRASSLAND MANAGEMENT                                *
*                                                                   *
* Version:      1.0                                                 *
*                                                                   *
* Date:         February 1992                                       *
* Author:       G.W.J. van de Ven                                   *
*                                                                   *
* Use of the model:                                                 *
*               With this model GRASMOD effects of grassland use and *
*               management on dry matter production, N uptake, K uptake, *
*               and N emissions can be calculated. Existing relations *
*               and knowledge are compiled in a consistent way.     *
* Modules:                                                          *
* --------                                                          *
* Subroutines: DIET                                                 *
*               DISTRI(bution)                                      *
*               FEED                                                *
* Functions:    AFGEN (Van Kraalingen)                              *
*                                                                   *
* Units:                                                            *
* ------------                                                      *
* 15 GRAS.DOC: the overall resluts of the calculations              *
* 20 GRAS.DAT: contains input data and results of the calculations  *
*               to be used in optimization                          *
* 25 GRAS.INP: file containing input data and can serve as input    *
*               file to GRASMOD                                     *
* 50 DIET.DOC: file containing results of the subroutine DIET, gives *
*               the feed ration for each of the summer periods and the *
*               total during the summer                             *
* 60 FEED.DOC: file containing results of the subroutine FEED, gives *
*               feeding value of herbage                            *
*                                                                   *
*==================================================================*
      PROGRAM GRASS
*---------------------------------------------------------------------
*     MAIN PROGRAM
*---------------------------------------------------------------------
*----- declaration of variables and constants

       IMPLICIT REAL (A - Z)
       DIMENSION  CKC(3,3), CKG(3,3), CNC(3,3), CNG(3,3), DCKC(3,3)
     *     , DCKG(3,3), DMA(3,3), DMCMX(3,3), DMGG(3,3), DMGMX(3,3)
```

```
     *    , DMTT(3,3), ENRGW(6), F(3,3), FLDMG(4), GF(4), GHLDMG(4)
     *    , KF(3,3), KM(3,3), KU(3,3), KUP(3,3), KUPC(3,3), KUPG(3,3)
     *    , NF(3,3), NM(3,3), NMC(3,3), NO3(3,3), NU(3,3)
     *    , NUP(3,3), NUPC(3,3), NUPG(3,3), TEADG(6), TKUPF(8)
     *    , TNDM1(36), TNDM2(36),TNDM3(36), TNO3F(18), TNUPF(14)

      INTEGER A, C, E, G, I, J, M, N, X, XX, Y, Z, NRB, NRN, NRC, NRM
     *         , CT

      CHARACTER*4       NMF(3,3)
      CHARACTER*60      NMGS(4)
      CHARACTER*70      TITTLE

*----- values of constants

      PARAMETER (AREAF=0.08/10000.,AREAU=0.68/10000.,C2=2300.,C3=3000.
     *     ,CKCON=0.015,CKM=0.017,CNM=0.0144,FLDMC=0.05,FNBLU=0.27
     *     ,FNH3F=0.13,FNH3G=0.03,FNH3U=0.13,FUPSEA=0.65,HLDMC=0.10
     *     ,KDP=9.,KRECI=0.70,KUPSL=175.,MAXDP=0.70,MAXNOM=0.95
     *     ,MAXNUS = 0.6,MEAT=60.,MF=10./12.,NDP=45.,NRECI=0.85
     *     ,NO3OM=13.,NOM=153.,PDCC=0.75,PDCM=0.56,SP= 184.)

      DATA (FLDMG(G), G=1,4)/
     *     2*0.02,2*0.0/
      DATA (GF(G), G=1,4)/
     *     2*0.0,1.0,0.5/
      DATA (GHLDMG(G), G=1,4)/
     *     2*0.07,0.20,0.14/
      DATA TKUPF/
     *     0.,0.,400.,280.,3000.,930.,20000.,930./
      DATA TNDM1/
     *     150., 5950.,175., 6900.,200., 7800.,225., 8600.,250., 9300.
     *    ,275., 9850.,300.,10300.,325.,10700.,350.,11000.,375.,11250.
     *    ,400.,11450.,425.,11600.,450.,11750.,475.,11850.,500.,11900.
     *    ,550.,12050.,600.,12200.,601.,12200./
      DATA TNDM2/
     *     150., 6600.,175., 7800.,200., 8800.,225., 9700.,250.,10450.
     *    ,275.,11150.,300.,11650.,325.,12100.,350.,12450.,375.,12750.
     *    ,400.,12950.,425.,13150.,450.,13300.,475.,13450.,500.,13550.
     *    ,550.,13700.,600.,13800.,601.,13800./
      DATA TNDM3/
     *     150., 7150.,175., 8450.,200., 9600.,225.,10600.,250.,11450.
     *    ,275.,12100.,300.,12750.,325.,13200.,350.,13550.,375.,13850.
     *    ,400.,14100.,425.,14350.,450.,14550.,475.,14700.,500.,14850.
     *    ,550.,14950.,600.,15000.,601.,15000./
      DATA TEADG/
     *      6000.,900.,10000.,1000.,14800.,1000./
      DATA TNUPF/
     *      0.,0.,200.,170.,400.,310.,500.,360.,600.,400.,900.,450.
     *     ,15000.,450./
```

```
      DATA TNO3F/
     *     0.,0.,100.,2.5,200.,9.6,300.,14.4,400.,43.,500.,91.,600.
     *    ,153.,1000.,560.,15000.,14560./
      DATA NMF/
     *     'U0F0','U1F0','U2F0','U0F1','U1F1','U2F1','U0F2'
     *     ,'U1F2','U2F2'/
      DATA NMGS/
     *     'zero grazing, no supply maize silage'
     *    ,'zero grazing, supply maize silage'
     *    ,'day and night grazing (no supply of maize silage)'
     *    ,'day grazing only (supply of maize silage)'/

*----- Initialisation

      Y  = 0

*----- input sources, open output files GRASN.DOC and GRASN.DAT

1     WRITE (*,'(1X,''Do you want input read from file? ''
     *       ,''(yes=1/no=2) : '',$)')
      READ (*,*,ERR=1) XX

2     WRITE (*,'(1X,''Do you want complete output? (yes=1/no=2) : ''
     *       ,$)')
      READ (*,*,ERR=2) X

      OPEN (UNIT       = 25
     *         ,FILE   = 'GRASN.INP'
     *         ,ACCESS = 'SEQUENTIAL'
     *         ,STATUS = 'OLD')

      OPEN (UNIT       = 15
     *         ,FILE   = 'GRASN.DOC'
     *         ,ACCESS = 'SEQUENTIAL'
     *         ,STATUS = 'OLD'
     *         ,FORM   = 'FORMATTED')

      OPEN (UNIT       = 20
     *         ,FILE   = 'GRASN.DAT'
     *         ,ACCESS = 'SEQUENTIAL'
     *         ,STATUS = 'OLD'
     *         ,FORM   = 'FORMATTED')

      OPEN (UNIT       =  40
     *         ,FILE   = 'DISTRI.OUT'
     *         ,ACCESS = 'SEQUENTIAL'
     *         ,STATUS = 'OLD'
     *         ,FORM   = 'FORMATTED')

      OPEN (UNIT       =  50
```

```
     *           ,FILE   = 'DIET.OUT'
     *           ,ACCESS = 'SEQUENTIAL'
     *           ,STATUS = 'OLD'
     *           ,FORM   = 'FORMATTED')
      WRITE(50,'(1X,''DIET.OUT: feed ration of dairy cows'',//)')

      OPEN (UNIT       =  60
     *           ,FILE   = 'FEED.OUT'
     *           ,ACCESS = 'SEQUENTIAL'
     *           ,STATUS = 'OLD'
     *           ,FORM   = 'FORMATTED')
      WRITE(60,'(1X,''FEED.OUT: feeding value of herbage'',//)')

      WRITE (20,'(1X,''GRASN.DAT: input data for LP-MGG''
     *            ,/,1X,''NRB NRN NRC NRM'')')
      IF (XX .EQ. 1) THEN
          READ (25,'(A70,//)') TITTLE
          READ (25,*) NRB,NRN,NRC,NRM
          WRITE (20,'(1X,I2,3I4,/)') NRB,NRN,NRC,NRM
          READ (25,'(/)')
      ENDIF


      WRITE (20,'(1X,'' B N C M      SR NH3T  NO3T  NSLU  MEAT   MILK''
     *        ,''  CONCS   ENRDCW   RDCPW    PNW MAXDMW''
     *        ,/,6X,''1 1'',3X,''NFERT''
     *        ,/,1X,'' 1    2 1'',3X,''MJDMC DCPDMC CNDMC MJADG DCPADG''
     *        ,/,1X,'' 1 1    1'',3X,''DMCDC''
     *        ,/,1X,'' 3'',6X,''MAISS'',/)')

****** Starting next iteration

1000  Y      = Y + 1
      WRITE(40,'(1X,''Y = '',I2)')Y
      WRITE(50,'(1X,''Y = '',I2)')Y
      IF (MOD(Y,10) .EQ. 1) THEN
         WRITE(60,'(T8,'' E CN   MJ    DVE  OEB  FDCP'')')
      ENDIF
      WRITE(60,'(1X,''Y = '',I2)')Y

*----- resetting variables to starting values

      Z      = 0
      RGD    = 0.
      DMTSUM = 0.
      DMGSUM = 0.
      NUPSUM = 0.
      NUPGSM = 0.
      NUPCSM = 0.
      NO3SUM = 0.
```

```
      KUPSUM = 0.
      KUPGSM = 0.
      KUPCSM = 0.

*----- reading input data

      IF (XX .EQ. 1) THEN
          READ (25,*,END=6000) G,N,C,M,NFERT,MP,MILK,CT
      ELSE
          WRITE (*,'(/,1X,''INPUT DATA GRASSLAND MANAGEMENT'')')
          WRITE (*,'(1X,I2,''-e iteratie'')') Y

10        WRITE (*,'(1X,A,T51,'': 1'',/,1X,A,T51,'': 2'',/
     *           ,1X,A,T51,'': 3'',/,1X,A,T51,'': 4'',/)') NMGS
          WRITE (*,'(1X,''Choose grassland management: '',$)')

          READ (*,*,ERR=10) G
          IF (G .LT. 1 .OR. G .GT. 4) GO TO 10

20        WRITE (*,'(1X,''N fertilizer application 650 kg ''
     *          ,''ha-1 yr-1) : '',$)')

          READ (*,*,ERR=20) NFERT
          IF (NFERT .LT. 0. .OR. NFERT .GT. 650.) GO TO 20

30        WRITE (*,'(1X,''Cutting percentage (maximum 500%) : '',$)')

          READ (*,*,ERR=30) MP
          IF (MP .GT. 500.) GO TO 30

50        WRITE (*,'(1X,''Milk production (5000, 6500, 8000 kg cow-1 ''
     *      ,''yr-1) : '',$)')

          READ (*,*,ERR=50) MILK
          IF (MILK.NE.5000. .AND. MILK.NE.6500. .AND. MILK.NE.8000.)
     *       GOTO 50

60        WRITE (*,'(1X,''Concentrate types: standard    = 0''
     *               ,/,''                  : low protein = 1): '',$)')

          READ (*,*,ERR=60) CT
          IF (CT .NE. 0 .AND. CT .NE. 1) GOTO 60
      ENDIF

      IF (MP .LT. 0.001) MP=0.001

****** dry matter production and nitrogen uptake
*----- uptake of N originating from deposition, mineralization and
*      fertilizers (kg ha-1 yr-1)
```

```
      BASNUP = (MAXDP*NDP + MAXNOM*NOM)*NRECI
      NUPFER = AFGEN(TNUPF,14,NFERT)
      NUPDMT = NUPFER + BASNUP

*----- amount of herbage consumed freshly and conserved

      IF (G .LE. 2) THEN
          DMGMAX = AFGEN(TNDM2,36,NUPDMT)
      ELSEIF (G .GT. 2 ) THEN
          DMGMAX = AFGEN(TNDM1,36,NUPDMT)
      ELSE
          WRITE (*,'(1X,''production cannot be calculated'')')
      ENDIF

      DMCMAX = AFGEN(TNDM3,36,NUPDMT)

      DMC    = 0.01*MP*C3

      IF (DMC .GE. DMCMAX) THEN
          DMC = DMCMAX
          MP  = 100.*DMC/C3
          WRITE (*,'(1X,''All grass is cut for conservation'',/
     *           ,1X,''The cutting percentage is '',F5.1)') MP
      ENDIF

*----- N uptake by fresh herbage and herbage for conservation

      NUPDMC = DMC/DMCMAX*NUPDMT

      IF (MP .LT. 1.) NUPDMC = 0.0


      NUPDMG = NUPDMT - NUPDMC
      DMG    = NUPDMG/NUPDMT*DMGMAX
      IF (DMG .LT. 0.001) DMG = 0.001

      DMT    = DMG + DMC

*----- N content in grazed and conserved grass

      CNDMG  = NUPDMG/DMG
      CNDMC  = NUPDMC/DMC

*----- Net herbage production (kg ha-1 yr-1)

      DMGDC  = (1.-GHLDMG(G)) * (1.-FLDMG(G))*DMG
      DMCDC  = (1.-HLDMC) * DMC

****** K management
```

```
*----- desired K content in grazed and conserved grass
*      according to 'Mineralenhandleiding'

       DCKDMG  = (47.75*CNDMG + 1.582)/100.
       DCKDMC  = (47.75*CNDMC + 1.582)/100.
       IF (CNDMG.EQ.0.) DCKDMG = 0.0
       IF (CNDMC.EQ.0.) DCKDMC = 0.0

*----- application of K and P fertilizers, according to the fertilizer
*      standards (kg ha-1 yr-1)

       IF (G .LE. 2) THEN
           IF (MP .LE. 100.) THEN
              KFERT = (140.*0.01*MP + 70*(1.-0.01*MP) + 100*(DMG -
     *                (1.-0.01*MP)*C2)/C2)*0.83
              PFERT = (45. + 20.*(DMG - (1.-0.01*MP)*C2)/C2)*0.437
           ELSE
              KFERT = (140. + 70.*(DMG + DMC - C3)/C2)*0.83
              PFERT = (45. + 20.*(DMG + DMC - C3)/C2)*0.437
           ENDIF
           GO TO 600

       ELSEIF (G .EQ. 3) THEN
           AK = 0.
           AP = 0.
       ELSEIF (G .EQ. 4) THEN
           AK = 90.
           AP = 30.
       ELSE
           WRITE (*,'(1X,''P and K application cannot be calculated'')')
       ENDIF

       IF (MP .LE. 100.) THEN
           PFERT = (45. + AP)*0.437
           KFERT = (140.*0.01*MP + 70. *(1.-0.01*MP) + AK)*0.83
       ELSE
           PFERT = (45. + 20.*(DMC - C3)/C3 +  AP)*0.437
           KFERT = (140. + 70.* (DMC - C3)/C3 + AK)*0.83
       ENDIF

600    CONTINUE

*----- K uptake from fertilizers, deposition and soil reserves

       KUPFER = AFGEN(TKUPF,8,KFERT)
       KUPKDP = MAXDP*KRECI*KDP
       KUPDMT = KUPSL + KUPKDP + KUPFER

*----- maximum K/N ratio is 1.4
```

```
      IF (KUPDMT .GE. 1.4*NUPDMT) THEN
          KUPDMT = 1.4*NUPDMT
          KUPFER = KUPDMT - KUPSL- KUPKDP
      ENDIF

      KUPDMG = NUPDMG/NUPDMT * KUPDMT
      KUPDMC = NUPDMC/NUPDMT * KUPDMT
      CKDMG  = KUPDMG/DMG
      CKDMC  = KUPDMC/DMC
      IF (CNDMG .EQ. 0.0) CKDMG = 0.0
      IF (CNDMC .EQ. 0.0) CKDMC = 0.0

2000  CONTINUE

****** loop to take account of additional herbage production and
*      N-uptake

      Z      = Z+1

*----- resetting starting values

      NUSUM  = 0.
      NFSUM  = 0.
      KUSUM  = 0.
      KFSUM  = 0.

*----- energy and protein feeding value and digestibility of conserved
*      herbage

      IF (NUPDMC .NE. 0.) THEN
         E = 1
         CALL FEED(Z,E,G,CNDMC,MJDMC,DVEDMC,OEBDMC,PDCGC)
      ENDIF

*----- energy and protein feeding value (MJ kg-1, g kg-1) and
*      digestibility (kg kg-1) of fresh herbage

      IF (G .LE. 2) THEN
          E = 2
      ELSE
          E = 3
      ENDIF

      IF (CNDMG.NE.0.) CALL FEED(Z,E,G,CNDMG,MJDMG,DVEDMG,OEBDMG,PDCG)

*----- digestible crude protein in artificially dried grass [kg dcp
*      kg-1 dm]

      CPADG  = 6.25*CNDMC*1000.
```

```
      DCPADG = (0.836*CPADG + 0.04*143. - 40. - 5.)
      MJADG = (6.9/1000.)*AFGEN(TEADG,6,DMGMAX)

*---- energy and dry matter intake from maize, grass and concentrates
*     by dairy cows during the summer period (MJ cow-1 d-1, kg cow-1
*     d-1), average N contents and digestibility of concentrates

      CALL DIET(Z,G,MILK,CT,MJDMG,DVEDMG,OEBDMG,GIDCS,MAIDCS,COIDCS
     *          ,MJMAIS,MJCON,CNCON,PDCC)

      SR  = DMGDC/GIDCS
      RGD = SR*SP
      D   = RGD*GF(G)


*---- Feed intake and N-intake by dairy cows with concentrates, maize
*     and grass in kg ha-1 in summer

      CONCS = COIDCS*SR
      MAISS = MAIDCS*SR

*---- in kg cow-1 d-1

      COIDC = COIDCS/SP
      MAIDC = MAIDCS/SP
      GIDC  = GIDCS/SP

      MJIDC = GIDC*MJDMG + MAIDC*MJMAIS + COIDC*MJCON

      NIC  = CONCS*CNCON
      NIM  = MAISS*CNM
      NIDC = CNDMG*DMGDC + NIC + NIM

*---- N incorporated in milk and meat and excreted with urine and
*     faeces (kg ha-1 yr-1)

      NPS   = SR*(0.535*MILK*0.0053 + SP/365.*MEAT*0.025)
      NEXDC = NIDC - NPS

*---- N in urine and in faeces (kg per excretion)

      NFT = (GIDC*CNDMG*(1.-PDCG) + COIDC*CNCON*(1.-PDCC) +
     *        MAIDC*CNM*(1.-PDCM))*RGD
      NUT = NEXDC - NFT

*---- amount of N deposited during grazing and collected
*     indoors as slurry (kg ha-1 yr-1)

      NUEXS = NUT/(12.*RGD)
      NFEXS = NFT/(12.*RGD)
```

```
      NUS   = NUT*GF(G)*MF
      NFS   = NFT*GF(G)*MF

      NSLUR = NUT - NUS + NFT - NFS

*----- K-intake by dairy cows in concentrates, maize and grass
*      (kg ha-1 yr-1)

      KIC   = CONCS*CKCON
      KIM   = MAISS*CKM
      KIDC  = CKDMG*DMGDC + KIC +KIM

*----- K incorporated in milk and meat and excreted with urine and
*      faeces (kg ha-1 yr-1)

      KPS   = SR*(0.535*MILK*0.0016 + SP/365.*MEAT*0.0020)
      KEXDC = KIDC - KPS

*----- K in urine and faeces (kg ha-1 yr-1, kg per excretion)

      KTU   = KEXDC*0.9
      KFT   = KEXDC - KTU
      KUEXS = KTU/(12.*RGD)
      KFEXS = KFT/(12.*RGD)
      KSU   = KTU*GF(G)*MF
      KFS   = KFT*GF(G)*MF
      KSLUR = KTU - KSU + KFT - KFS

      IF (G .LE. 2 .OR. DMG .LE. 0.001) GO TO 5000

*----- distribution of faeces and urine over the field:

      CALL DISTRI (D,AREAF,AREAU,F,FREST)

****** amount of N and K deposited with urine (I) and faeces (J) to
*      the various parts of the field

      DO 100 I = 1,3
         DO 200 J = 1,3

            NU(I,J) = NUEXS/AREAU*(I-1)
            NF(I,J) = NFEXS/AREAF*(J-1)
            NUSUM   = NUSUM + NU(I,J)*F(I,J)
            NFSUM   = NFSUM + NF(I,J)*F(I,J)

            KU(I,J) = KUEXS/AREAU*(I-1)
            KF(I,J) = KFEXS/AREAF*(J-1)
            KUSUM   = KUSUM + KU(I,J)*F(I,J)
            KFSUM   = KFSUM + KF(I,J)*F(I,J)
```

```
      IF (Z .GT. 1) GO TO 3000

*----- urinepatch: inorganic N application (kg ha-1 yr-1)

      NM(I,J)  = NFERT + MAXNUS*NU(I,J)
      NMC(I,J) = NFERT + MAXNUS*FUPSEA*NU(I,J)

*----- N uptake by herbage in a urine patch (kg ha-1 yr-1)

      NUP(I,J) = BASNUP + AFGEN(TNUPF,14,NMC(I,J))

*----- additional dry matter production in a urine patch (kg ha-1 yr-1)


      DMGMX(I,J) = AFGEN(TNDM1,36,NUP(I,J))
      DMCMX(I,J) = AFGEN(TNDM3,36,NUP(I,J))

      NUPC(I,J)  = DMC/DMCMX(I,J)*NUP(I,J)
      IF (MP .LT. 1.) NUPC(I,J) = 0.0
      NUPG(I,J)  = NUP(I,J) - NUPC(I,J)

      DMGG(I,J)  = NUPG(I,J)/NUP(I,J)*DMGMX(I,J)
      DMTT(I,J)  = DMGG(I,J) + DMC

      CNG(I,J)   = NUPG(I,J)/DMGG(I,J)
      CNC(I,J)   = NUPC(I,J)/DMC
      DCKG(I,J)  = (47.75*CNG(I,J) + 1.582)/100.
      DCKC(I,J)  = (47.75*CNC(I,J) + 1.582)/100.


*----- total amount of K available for uptake by the grass in urine and
*      faeces patches (kg ha-1 yr-1)

      KM(I,J) = KFERT + (KU(I,J) + KF(I,J))*FUPSEA
      KUPMAX  = KUPSL + KUPKDP + AFGEN(TKUPF,8,KM(I,J))

*----- K uptake and K content of herbage in patches (kg ha-1 yr-1,
*      kg kg-1)

      KUPP     = 1.4*NUP(I,J)
      KUP(I,J) = MIN(KUPP,KUPMAX)

      KUPC(I,J) = DMC/DMCMX(I,J)*KUP(I,J)
      IF (MP .LT. 1.) KUPC(I,J) = 0.
      KUPG(I,J) = KUP(I,J) - KUPC(I,J)

      CKG(I,J)  = KUPG(I,J)/DMGG(I,J)
      CKC(I,J)  = KUPC(I,J)/DMC

*----- total dm production, N and K uptake (kg ha-1 yr-1)
```

```
            DMTSUM = DMTSUM + DMTT(I,J)*F(I,J)
            DMGSUM = DMGSUM + DMGG(I,J)*F(I,J)
            NUPSUM = NUPSUM + NUP(I,J)*F(I,J)
            NUPGSM = NUPGSM + NUPG(I,J)*F(I,J)
            NUPCSM = NUPCSM + NUPC(I,J)*F(I,J)
            KUPSUM = KUPSUM + KUP(I,J)*F(I,J)
            KUPGSM = KUPGSM + KUPG(I,J)*F(I,J)
            KUPCSM = KUPCSM + KUPC(I,J)*F(I,J)

3000    CONTINUE

200         CONTINUE
100     CONTINUE

****** area covered more than twice with urine or faeces

*----- N and K in faeces and urine on FREST (kg ha-1 yr-1)

        NUREST = (NUS-NUSUM)/FREST
        NFREST = (NFS-NFSUM)/FREST
        NUSUM  = NUSUM + NUREST*FREST
        NFSUM  = NFSUM + NFREST*FREST

        KUREST = (KSU-KUSUM)/FREST
        KFREST = (KFS-KFSUM)/FREST
        KUSUM  = KUSUM + KUREST*FREST
        KFSUM  = KFSUM + KFREST*FREST

        IF (Z .GT. 1) GO TO 4000

*----- FREST: inorganic N application(kg ha-1 yr-1)

        NREST  = NFERT + MAXNUS*NUREST
        NCREST = NFERT + MAXNUS*FUPSEA*NUREST

*----- dry matter production and N uptake on FREST (kg ha-1 yr-1)

        NUPRST = BASNUP + AFGEN(TNUPF,14,NCREST)

        DMGMXR = AFGEN(TNDM1,36,NUPRST)
        DMCMXR = AFGEN(TNDM3,36,NUPRST)

        NUPCR  = DMC/DMCMXR*NUPRST
        IF (MP .LT. 1.) NUPCR = 0.0
        NUPGR  = NUPRST - NUPCR

        DMGRST = NUPGR/NUPRST*DMGMXR
        DMARST = DMGRST - DMG
        CNGR   = NUPGR/DMGRST
```

```
      CNCR   = NUPCR/DMC

      DCKGR  = (47.75*CNGR + 1.582)/100.
      DCKCR  = (47.75*CNCR + 1.582)/100.

      DMTRST = DMGRST + DMC

*----- content and K uptake on FREST (kg kg-1, kg ha-1 yr-1)

      KMREST = KFERT + (KUREST + KFREST)*FUPSEA
      KUPMAX = KUPSL + KUPKDP + AFGEN(TKUPF,8,KMREST)
      KUPP   = 1.4*NUPRST

      KUPRST = MIN(KUPP,KUPMAX)
      KUPCR  = DMC/DMCMXR*KUPRST
      KUPGR  = KUPRST - KUPCR

      CKGR   = KUPGR/DMGRST
      CKCR   = KUPCR/DMC

*----- total dry matter production and N and K uptake (kg ha-1 yr-1)

      DMTSUM = DMTSUM + DMTRST*FREST
      DMGSUM = DMGSUM + DMGRST*FREST
      NUPSUM = NUPSUM + NUPRST*FREST
      NUPCSM = NUPCSM + NUPCR*FREST
      NUPGSM = NUPGSM + NUPGR*FREST
      KUPSUM = KUPSUM + KUPRST*FREST
      KUPGSM = KUPGSM + KUPGR*FREST
      KUPCSM = KUPCSM + KUPCR*FREST

      DME    = DMTSUM - DMT
      NUPE   = NUPSUM - NUPDMT
      KUPE   = KUPSUM - KUPDMT

*----- Dry matter production, N + K uptake and N + K content in
*      freshly consumed grass corrected for N + K appliction by urine
*      (kg ha-1 yr-1, kg kg-1)

      DMG    = DMGSUM
      DMGDC  = DMG*(1. - GHLDMG(G))*(1. - FLDMG(G))

      NUPDMG = NUPGSM
      CNDMG  = NUPDMG/DMG
      NUPDMC = NUPCSM
      CNDMC  = NUPDMC/DMC

      DCKDMG = (47.75*CNDMG + 1.582)/100.
      DCKDMC = (47.75*CNDMC + 1.582)/100.
      IF (CNDMC .EQ. 0.) DCKDMC = 0.
```

```
      KUPDMG = NUPGSM/NUPSUM*KUPSUM
      KUPDMC = KUPSUM - KUPDMG
      CKDMG  = KUPDMG/DMG
      CKDMC  = KUPDMC/DMC

****** loop to take account of additional herbage and N-uptake
4000  CONTINUE

      IF (Z .LT. 2) GO TO 2000
*----- utilization of urine-N applied and urine-N excreted and K
*      applied in faeces and urine

      FNUUP  = NUPE/NUS
      FKUFP  = KUPE/(KSU+KFS)

5000  CONTINUE

****** Nitrate leaching

C----- leaching of NO3-N due to N fertilization (kg ha-1 yr-1)

      NO3FER = AFGEN(TNO3F,18,NFERT)

C----- total leaching of NO3-N  (kg ha-1 yr-1)

      IF (G .LE. 2 .OR. DMG .LE. 0.001) THEN
          NO3T = NO3OM + NO3FER
      ELSE
          DO 80 I = 1,3
             DO 90 J = 1,3
                NO3(I,J) = AFGEN(TNO3F,18,NM(I,J)) + NO3OM
                NO3SUM   = NO3SUM + NO3(I,J)*F(I,J)
90           CONTINUE
80        CONTINUE

          NO3RST = AFGEN(TNO3F,18,NREST) + NO3OM

          NO3SUM = NO3SUM + NO3RST*FREST

          NO3T   = NO3SUM
          NO3E   = NO3T - NO3OM - NO3FER
      ENDIF


*----- total dry matter production and N + K uptake (kg ha-1 yr-1)

      DMT    = DMG + DMC
      NUPDMT = NUPDMG + NUPDMC
      KUPDMT = KUPDMG + KUPDMC
```

```
****** N management

*----- N in grazing/harvesting and feeding losses (kg ha-1 yr-1)

       NGHLOS = NUPDMG*GHLDMG(G) + NUPDMC*HLDMC
       NFLOS  = NUPDMG*(1.-GHLDMG(G))*FLDMG(G)
       NSLURF = NSLUR + NFLOS

****** volatilization of NH3-N from faeces, urine and decaying herbage
*      (kg ha-1 yr-1)

       NH3US  = FNH3U*NUS
       NH3FS  = FNH3F*NFS
       NH3DG  = FNH3G*NGHLOS

*----- total volatilization of NH3-N

       NH3T  = NH3US + NH3FS + NH3DG

*----- N balance loss in urine patches

       NBLU  = FNBLU*NUS

****** K management

*----- K in grazing/feeding losses (kg ha-1 yr-1)

       KGHLOS = KUPDMG*GHLDMG(G) + KUPDMC*HLDMC
       KFLOS  = KUPDMG*(1.-GHLDMG(G))*FLDMG(G)
       KSLUR  = KSLUR + KFLOS

****** Balance

*----- N losses from fertilizers, mineralization, deposition and grazing
*      and feeding losses not accounted for in identified processes
*      (kg ha-1 yr-1)

       LNOMDP = NOM + NDP - BASNUP - NO3OM
       LNFERT = NFERT - NUPFER - NO3FER
       LNG    = NGHLOS - NH3DG

*----- N losses from faeces and urine not accounted for (kg ha-1 yr-1)

       LNUS   = NUS - NH3US - NO3E - NUPE - NBLU
       LNFS   = NFS - NH3FS

*----- N balance soil

       NMU    = NUS - NH3US - NBLU
```

```
      INORNI = NOM + NDP + NFERT + NMU
      NIMM   = LNUS + LNFERT + LNOMDP
      INORNO = NUPDMT + NO3T + NIMM
      ORNI   = LNG + LNFS + NIMM
      NSURPL = ORNI - NOM
      ORNO   = NOM + NSURPL

*----- total N inputs and outputs and a balance row (kg ha-1 yr-1)

      NPOOL  = LNOMDP + LNFERT + LNG + LNUS + LNFS
      NOUTPT = NO3T + NH3T + NBLU + NPS + NSLURF + DMCDC*CNDMC
      NINPUT = NDP + NOM + NFERT + NIC + NIM

*----- K losses from fertilizers, mineralization, deposition, grazing
*      and feeding losses and faeces and urine not accountedd for
*      (kg ha-1 yr-1)

      LKFERT = KFERT - KUPFER
      LKDP   = KDP - KUPKDP
      LKG    = KGHLOS
      LKUFS  = KSU + KFS - KUPE

*----- total K inputs and outputs and a balance row (kg ha-1 yr-1)

      KLOSS  = LKFERT + LKDP + LKG + LKUFS
      KSLIN  = KUPSL + KDP + KFERT + KSU + KFS + KGHLOS
      KSURPL = KLOSS - KUPSL
      KSLOUT = KUPSL + KUPDMT + KSURPL

      KOUTPT = KPS + KSLUR + DMCDC*CKDMC
      KINPUT = KDP + KUPSL +KFERT +KIC + KIM

****** results in GRASN.DAT input file for LP

      WRITE (20,'(1X,4I2,F8.2,F5.0,3F6.0,2F7.0,2F9.0,F6.0,F7.0)')
     *       G,N,C,M,SR,NH3T,NO3T,NSLURF,MEAT*SR,MILK*SR,CONCS,ENRDCW
     *       ,RDCPW,NPW,MAXDMW
      IF (M.EQ.1 .AND. C.EQ.1) WRITE(20,'(10X,F7.0)') NFERT
      IF (M.EQ.1 .AND. G.LE.2 .AND. C.EQ.2) WRITE(20,'(10X,F7.3,2F6.4
     *   ,F6.3,F6.4)') MJDMC,DCPDMC,CNDMC,MJADG,DCPADG
      IF (M.EQ.1 .AND. G.LE.2 .AND. N.EQ.1) WRITE(20,'(10X,F6.0)')
     *    DMCDC
      IF (G.EQ.4) WRITE(20,'(10X,F6.0)') MAISS

      IF (X .EQ. 2) GO TO 40

****** results in GRASN.DOC

      WRITE (15,'(
     *      ''RESULTS GRASSLAND MANAGEMENT MODEL'',//
```

```
*      ,''INPUTS'',/,''- grassland management'',T30,'': '',A,/
*      ,''- N fertilizer rate          : '',F6.0,/
*      ,''- cutting percentage'',T30,'': '',F6.0,/
*      ,''- milk production per cow    : '',F6.0,/
*      ,''- type of concentrate        : '',I6,/)')
*      NMGS(G),NFERT,MP,MILK,CT

  WRITE (15,'(
*        ''RESULTS'',//,''GRASSLAND'',/,T22,''total'',T32
*      ,''fresh'',T42,''silage'')')

  WRITE (15,'(
*        ''dm gross'',T17,3F10.0,/,''   nett'',T17,3F10.0,/
*      ,''N uptake'',T17,3F10.0,/,''N content'',T29,2F10.2,/
*      ,''K uptake'',T17,3F10.0,/,''K content'',T29,2F10.2,/
*      ,''desired K content'',T29,2F10.2,/
*      ,''leaching'',T17,F10.0,/,''volatilization'',T23,F4.0,/
*      ,''utilization urine-N'',F8.1,/,''utilization u+f K'',F10.1
*      ,/,''N fertilizer'',T17,F10.0,/,''K fertilizer'',T17,F10.0,/
*      ,''P fertilizer'',T17,F10.0,/,''stocking rate'',T27,F14.4,/)
*      ')DMT,DMG,DMC,DMGDC+DMCDC,DMGDC,DMCDC,NUPDMT
*      ,NUPDMG,NUPDMC,CNDMG*100.,CNDMC*100.,KUPDMT,KUPDMG,KUPDMC
*      ,CKDMG*100.,CKDMC*100.,DCKDMG*100.,DCKDMC*100.
*      ,NO3T,NH3T,FNUUP*100.,FKUFP*100.,NFERT,KFERT
*      ,PFERT,SR

  WRITE (15,'(
*        ''DAIRY COWS'',/,T20,''total'',T31,''grass'',T41,''maize''
*      ,T51,''concentrates'')')

  WRITE (15,'(
*        ''milkproduction'',F10.0,/,''meatproduction'',F10.0,/
*      ,''intake per day (kg)'',F6.1,3F10.1,/,''energy (MJ)''
*      ,T17,4F10.2
*      ,/,''nitrogen (kg)'',T18,4F10.3,/)')
*      0.535*MILK*SR,SP/365.*MEAT*SR,GIDC+COIDC+MAIDC,GIDC
*      ,MAIDC,COIDC,MJIDC,GIDC*MJDMG,MAIDC*MJMAIS,COIDC*MJCON
*      ,NIDC/RGD,GIDC*CNDMG,MAIDC*CNM,COIDC*CNCON

  WRITE (15,'(
*        ''N BALANCE GRASSLAND (kg ha-1 yr-1)'',/,T30,''uptake'',T40
*      ,''leaching'',T50,''volatil.'', T60,''balance'',T70
*      ,''organic'',T80,''immobil.'',/,T20
*      ,''total'',T30,''herbage'',T40,''NO3-N'',T50,''NH3-N'',T60
*      ,''loss'', T70,''N soil'',T80,''(inorg.N)'')')

  WRITE (15,'(
*        ''mineralization'',T20,F4.0,2F10.0,T80,F4.0,/
*      ,''deposition'',T20,F4.0,F10.0,/,''fertilizer''
*      ,T14,3F10.0,T80,F4.0)')
```

```
     *       NOM,NRECI*MAXNOM*NOM,NO3OM,LNOMDP,NDP,NRECI*MAXDP*NDP
     *      ,NFERT,NUPFER,NO3FER,LNFERT

      WRITE (15,'(
     *       ''urine'',T14,5F10.0,T80,F4.0,/,''faeces'',T20
     *      ,F4.0,T44,F10.0,T70,F4.0/,''grazing/harvesting'',T20,F4.0
     *      ,T44,F10.0,T70,F4.0/,''   losses'',/,''total''
     *      ,T24,6F10.0,/)')
     *       NUS,NUPE,NO3E,NH3US,NBLU,LNUS,NFS,NH3FS,LNFS,NGHLOS
     *      ,NH3DG,LNG,NUPDMT,NO3T,NH3T,NBLU,LNG+LNFS,NIMM

      WRITE (15,'(
     *       ''N BALANCE SOIL (kg ha-1 yr-1)'',//,''INORGANIC N'',T20
     *      ,''in'',T55,''out'',/
     *      ,''mineralisation'',T19,F5.0,T35,''uptake herbage'',T54
     *      ,F5.0,/,''deposition'',T19,F5.0,T35,''leaching'',T54,F5.0,/
     *      ,''fertilizer'',T19,F5.0,T35,''immobilisation'',T54,F5.0,/
     *      ,''urine'',T19,F5.0,//,''total'',T19,F5.0,T35,''total'',T54
     *      ,F5.0,/)')NOM,NUPDMT,NDP,NO3T,NFERT,NIMM,NMU,INORNI,INORNO

      WRITE (15,'(
     *       ''ORGANIC N'',T20,''in'',T55,''out'',/,''immobilisation''
     *      ,T19,F5.0,T35
     *      ,''mineralisation'',T54,F5.0,/,''faeces'',T19,F5.0,T35
     *      ,''surplus'',T54,F5.0,/,''grazing/harvesting'',T19,F5.0,/
     *      ,''   losses'',/,''total'',T19,F5.0,T35,''total'',T54,F5.0
     *      ,/)')NIMM,NOM,LNFS,NSURPL,LNG,ORNI,ORNO

C       IF (G .LE. 2) GO TO 500

      WRITE (15,'(
     *       ''N BALANCE DAIRY COWS (kg ha-1 yr-1)'',/,T20,''total''
     *      ,T30,''grass'',T40,''maize'',T50,''concentrates'',T65
     *      ,''type (%N)'',/,''intake'',T14,4F10.0,F15.2)')NIDC
     *      ,CNDMG*DMGDC,NIM,NIC,CNCON*100.

      WRITE (15,'(
     *       T20,''total'',T30,''urine'',T40,''faeces'',T50
     *      ,''milk/meat'')')

      WRITE (15,'(
     *       ''excretion'',T14,4F10.0,/,''field'',T20,F4.0,2F10.0
     *      ,/,''stable'',T20,F4.0,2F10.0,/)')
     *      NIDC,NUT,NFT,NPS,NUS+NFS,NUS,NFS,NSLUR,NUT-NUS,NFT-NFS

500   WRITE (15,'(
     *       ''INPUT/OUTPUT TABLE N'',//,''INPUT'',T35,''OUTPUT'',/
     *      ,''deposition'',T20,F4.0,T35,''milk+meat'',T55,F4.0,/
     *      ,''mineralization'',T20,F4.0,T35,''leaching'',T55,F4.0,/
     *      ,''fertilizer'',T20,F4.0,T35,''volatilization'',T55,F4.0,/
```

```
     *       ,''maize+concentrates'',T20,F4.0,T35,''balance loss'',T55
     *       ,F4.0,/,T35,''slurry'',T55,F4.0,/
     *       ,T35,''silage'',T55,F4.0,/,T35,''organic N pool'',T55
     *       ,F4.0,//,''total'',T20,F4.0,T35,''total'',T55,F4.0)')
     *        NDP,NPS,NOM,NO3T,NFERT,NH3T,NIC+NIM,NBLU,NSLURF,DMCDC*CNDMC
     *       ,NPOOL,NINPUT,NOUTPT+NPOOL

        WRITE (15,'(/
     *        ''K BALANCE GRASS (kg ha-1 yr-1)'',/,T30,''plant'',T20
     *       ,''total'',T30,''uptake'',T40,''not accounted for'')')

        WRITE (15,'(
     *        ''soil input'',T20,F4.0,F10.0,/,''deposition'',T20,F4.0
     *       ,2F10.0,/,''fertilizer'',T14,3F10.0)')
     *        KUPSL,KUPSL,KDP,KUPKDP,LKDP,KFERT,KUPFER,LKFERT

        WRITE (15,'(
     *        ''urine + faeces'',T20,F4.0,2F10.0/
     *       ,''grazing/harvesting'',T20,F4.0,T40,F4.0,/,''   losses'',/
     *       ,''total'',T24,2F10.0,/)')
     *        KSU+KFS,KUPE,LKUFS,KGHLOS,LKG,KUPDMT,KLOSS

        IF (G .LE. 2) GO TO 700

        WRITE (15,'(
     *        ''K BALANCE DAIRY COWS (kg ha-1 yr-1)'',/,T20,''total''
     *       ,T30,''grass'',T40,''maize'',T50,''concentrates'',/
     *       ,''intake'',T14,4F10.0)')KIDC,CKDMG*DMGDC,KIM,KIC

        WRITE (15,'(
     *        T20,''total'',T30,''urine'',T40,''faeces'',T50
     *       ,''milk/meat'')')

        WRITE (15,'(
     *        ''excretion'',T14,4F10.0,/,''field'',T20,F4.0,2F10.0
     *       ,/,''stable'',T20,F4.0,2F10.0,/)')
     *       KIDC,KTU,KFT,KPS,KSU+KFS,KSU,KFS,KSLUR,KTU-KSU,KFT-KFS

 700    WRITE (15,'(
     *        ''K BALANCE SOIL (kg ha-1 yr-1)'',//,T20,''in'',T55
     *       ,''out'',/,''mineralisation'',T20,F4.0,T35
     *       ,''uptake herbage'',T55,F4.0,/
     *       ,''deposition'',T20,F4.0,T35,''mineralisation'',T55,F4.0,/
     *       ,''fertilizer'',T20,F4.0,T35,''surplus'',T55,F4.0,/
     *       ,''urine+faeces'',T20,F4.0,/,''grazing/harvesting'',T20
     *       ,F4.0,/,''   losses'',/,''total'',T20,F4.0,T35,''total''
     *       ,T55,F4.0,/)')KUPSL,KUPDMT,KDP,KUPSL,KFERT,KSURPL
     *       ,KSU+KFS,KGHLOS,KSLIN,KSLOUT
```

```
      WRITE (15,'(
     *       ''INPUT/OUTPUT TABLE K'',//,''INPUT'',T35,''OUTPUT'',/
     *      ,''deposition'',T20,F4.0,T35,''milk+meat'',T55,F4.0,/
     *      ,''soil input'',T20,F4.0,T35,''slurry'',T55,F4.0,/
     *      ,''fertilizer'',T20,F4.0,T35,''silage'',T55,F4.0,/
     *      ,''maize+concentrates'',T20,F4.0,T35,''surplus''
     *      ,T55,F4.0,//,''total'',T20,F4.0,T35,''total'',T55,F4.0)')
     *       KDP,KPS,KUPSL,KSLUR,KFERT,DMCDC*CKDMC,KIC+KIM,KLOSS
     *      ,KINPUT,KOUTPT+KLOSS

      IF (G .LE. 2 .OR. DMG .LE. 0.001) GO TO 40

      WRITE (15,'(/,
     *       ''DETAILS OF URINE AND FAECES PATCHES'',//
     *      ,T15,''dry'',T24,''N'',T31,''N'',T37,''N'',T56,''K'',T63
     *      ,''K'',T69,''K'',T80,''desired'',/,T7,''part   matter  ''
     *      ,''urine  faeces upt.  % N   NO3   urine  faeces upt.''
     *      ,''  % K   % K'')')

      DO 300 I = 1,3
         DO 400 J = 1,3
            WRITE (15,'(
     *           A4,F7.4,F8.0,2F7.0,F6.0,F6.2,F6.0,2F7.0,F6.0,2F6.2)')
     *           NMF(I,J),F(I,J),DMTT(I,J),NU(I,J),NF(I,J),NUP(I,J)
     *          ,CNG(I,J)*100.,NO3(I,J),KU(I,J),KF(I,J)
     *          ,KUP(I,J),CKG(I,J)*100.,DCKG(I,J)*100.
400     CONTINUE
300   CONTINUE

      WRITE (15,'(
     *      ''REST'',F7.4,F8.0,2F7.0,F6.0,F6.2,F6.0,2F7.0,F6.0,2F6.2)')
     *       FREST,DMTRST,NUREST,NFREST,NUPRST,CNGR*100.
     *      ,NO3RST,KUREST,KFREST,KUPRST,CKGR*100.,DCKGR*100.

      WRITE (15,'(/,
     *       ''av.  1.0000'',F8.0,2F7.0,F6.0,F6.2,F6.0,2F7.0,F6.0,2F6.2
     *      ,/)')DMTSUM,NUS,NFS,NUPSUM,100.*CNDMG,NO3SUM,KSU
     *      ,KFS,KUPSUM,100.*CKDMG,DCKDMG*100.


****** continue with new calculations or stop?

40    IF (XX .EQ. 1) THEN
          A = 1
      ELSE
          WRITE (*,'(1X,''do you want to continue? (yes=1/no=2) : ''
     *           ,$)')
          READ (*,*,ERR=40) A
          IF (A.LT.1.OR.A.GT.2) GO TO 40
      ENDIF
```

```
      IF (A.EQ.1) THEN
          GO TO 1000
      ELSEIF (A.EQ.2) THEN
          GO TO 6000
      ELSE
          GO TO 40
      ENDIF

6000  CLOSE(UNIT=25)
      CLOSE(UNIT=15)
      CLOSE(UNIT=20)
      CLOSE(UNIT=40)
      CLOSE(UNIT=50)
      CLOSE(UNIT=60)

      END

*-----------------------------------------------------------------------
*    FUNCTIONS
*-----------------------------------------------------------------------
*  REAL FUNCTION AFGEN                                                 *
*  Author : Daniel  van Kraalingen                                     *
*  Date   : 18-FEB-1987                                                *
*  Purpose: This function is a linear interpolation function.  The     *
*           function does not extrapolate : in case of X below or      *
*           above the region defined by TABLE, the first               *
*           respectively the last Y-value is returned and a message    *
*           is generated.                                              *
*                                                                      *
*  FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)     *
*  name    meaning                                     units  class    *
*  ----    -------                                     -----  -----    *
*  AFGEN  function name, result of the interpolation    =      O       *
*  TABLE  A one-dimensional array with paired           =      I       *
*         data: x,y,x,y, etc.                                          *
*  ILTAB  The number of elements of the array           -      I       *
*         TABLE                                                        *
*  X      The value at which interpolation should       =      I       *
*         take place                                                   *
*                                                                      *
*  FATAL ERROR CHECKS (execution terminated, message)                  *
*  condition                                                           *
*  ---------                                                           *
*  TABLE(I) < TABLE(I-2) , for I odd                                   *
*  ILTAB odd                                                           *
*                                                                      *
*  SUBROUTINES called : none                                           *
*  FILE usage : none                                                   *
*----------------------------------------------------------------------*
```

```
      REAL FUNCTION AFGEN (TABLE,ILTAB,X)
      IMPLICIT REAL (A-Z)
      INTEGER I, IUP, ILTAB
      DIMENSION TABLE(ILTAB)

*------      check on odd ILTAB

      IF (MOD(ILTAB,2).NE.0) THEN
         WRITE (*,'(A,I4/,A)')
     1         ' ERROR in function AFGEN : ILTAB=',ILTAB,
     2         ' ILTAB must be even !'
        STOP
      ENDIF

      IUP = 0
      DO 10 I=3,ILTAB,2

*--------- check on ascending order of X-values in function
        IF (TABLE(I).LE.TABLE(I-2)) THEN
             WRITE (*,'(A,I4/,A,I4,A/,A)')
     1            ' X-coordinates not in ascending order at element',I,
     2            ' AFGEN-function contains',ILTAB,' points',
     3            ' Run deleted!'
            STOP
         ENDIF
         IF (IUP.EQ.0.AND.TABLE(I).GE.X) IUP = I
10      CONTINUE

      IF (X.LT.TABLE(1)) THEN
         WRITE (*,'(A/A,I4,A/A,G8.2)')
     1            ' Interpolation below defined region!!',
     2            ' AFGEN-function contains ',ILTAB,' points,',
     3            ' Interpolation at X=',X
         AFGEN = TABLE(2)
         GOTO 40
      END IF

      IF (X.GT.TABLE(ILTAB-1)) THEN
       WRITE (*,'(A/A,I4,A/A,G8.2)')
     1           ' Interpolation above defined region!!',
     2           ' AFGEN-function contains ',ILTAB,' points,',
     3           ' Interpolation at X=',X
        AFGEN = TABLE(ILTAB)
        GO TO 40
      END IF
      SLOPE = (TABLE(IUP+1)-TABLE(IUP-1))/(TABLE(IUP)-TABLE(IUP-2))
      AFGEN = TABLE(IUP-1)+(X-TABLE(IUP-2))*SLOPE

40    RETURN
```

2.b Subroutine FEED

```
      SUBROUTINE FEED(Z,E,G,CN,MJ,DVE,OEB,FDCP)
*---------------------------------------------------------------------
*     Calculation of the nutritive value  with regard to both energy
*     and protein content and the digestibility of herbage according
*     to the new protein valuation system
*---------------------------------------------------------------------
      IMPLICIT REAL (A - Z)
      DIMENSION CASH(3),CF(3),DAY(3),FP(3),HARV(3)
      INTEGER E,G,Z

      PARAMETER (CFAT = 40., GE = 18410., DM = 450.)

      DATA (CF(E),E=1,3)   /245.,215.,205./
      DATA (DAY(E),E=1,3)  /61.,2*91./
      DATA (FP(E),E=1,3)   /95.,2*0./
      DATA (HARV(E),E=1,3) /54.,2*63./

      CP = CN*6.25*1000.

      CASH(1) = 0.144*CP + 86.
      CASH(2) = 0.144*CP + 60.
      CASH(3) = 0.144*CP + 65.

      IF (E .EQ. 1)THEN
          DCP  = 0.895*CP + 0.04*CASH(E) - 40. - 5.
          DOM  = 1063 - 0.77*CF(E) - 1.23*CASH(E) - 0.03*DM - HARV(E)
          PBRE = 19.8 - 0.077*CP + 0.071*DAY(E) + 0.031*DM
          PRRE = 19.0 - 0.066*CP + 0.025*DAY(E) + 0.006*DM
      ELSE
          DCP  = 0.959*CP + 0.04*CASH(E) - 40. - 2.
          DOM  = 1058 - 0.74*CF(E) - 1.12*CASH(E) - HARV(E)
          PBRE = 38.6 - 0.08*CP + 0.07*DAY(E)
          PRRE = 10.2 - 0.037*CP + 0.022*DAY(E)
      ENDIF

*----- Energy value of herbage

      ME = 14.23*DOM + 5.86*DCP
      Q  = 100.*ME/GE
      MJ = (0.6*(1. + 0.004*(Q-57.))*0.9752*ME)/1000.

*----- fraction digestible crude protein
      FDCP  = DCP/CP

*----- DVE-waarden (g kg-1)

      PDVBE = (PBRE - PRRE)/PBRE*100.
      DVBE  = 1.1*(CP*PBRE/100.)*(PDVBE/100.)
      FOS   = DOM - CFAT - CP*(PBRE/100.) - FP(E)
```

```
      DVME  = FOS*0.150*0.75*0.85
      DVMFE = (1000. - DOM - CASH(E)*0.5)*0.075
      DVE   = DVBE + DVME - DVMFE

*----- OEB-waarde (g kg-1)

      OEB   = CP*(1. - 1.11*PBRE/100.) - FOS*0.150

      IF ((Z.EQ.1 .AND. G .LE.2) .OR. (Z .EQ.2)) THEN
         WRITE(60,'(T8,I2,F5.3,F6.3,2F5.0,F5.3,/)')E,CN,MJ,DVE,OEB,FDCP
      ENDIF

      RETURN
      END
```

2.c Subroutine DIET

```
      SUBROUTINE DIET(Z,G,MILK,CT,MJDMG,DVEDMG,OEBDMG,GIDCS,MAIDCS
     *                ,COIDCS,MJMAIS,MJCON,CNCON,PDCC)
*----------------------------------------------------------------------
*     calculation of the ration of dairy cows during the summer

      IMPLICIT REAL (A-Z)
      DIMENSION CN(4),CP(4),CI(4),CON(2,4),COIDC(2),CONIDC(3),CONRDC(2)
     *    ,DCPI(2),DMIMAX(2),DSIDC(2),DVEC(4),DVEIC(2),DVEIF(2)
     *    ,DVERC(2),DVERP(2),DVERT(2),ENRC(2),ENRF(3),ENRP(2),DVES(2)
     *    ,ENRS(4),ENRT(2),FDCP(4),FSYS(4),GIDC(2),MAIDC(4),MAXI(2)
     *    ,MJDMGP(2),MILKD(2,3),MJCONC(3),CPI(2),OEBC(4),OEBIC(2)
     *    ,OEBIF(2),OEBIT(2),PERIOD(2),R(2),RC(3),RCON(2),RM(2)
     *    ,SW(2)
      INTEGER C, G, M, P, I, Z, CT

      PARAMETER (ENRM=34.63, ENRG=1.28,SWG=0.55, SWM=0.65, DVERM=121.
     *     , DVEMAI=47., OEBMAI=-16.)

      DATA (CN(C), C=1,4)            /0.014,0.029,0.023,0.022/
      DATA (FDCP(C), C=1,4)          /0.65,0.75,0.65,0.70/
      DATA (DVEC(C), C=1,4)          /64.,100.,100.,60./
      DATA (DVERC(P), P=1,2)         /0.,13./
      DATA (ENRC(P), P=1,2)          /0.25,1.35/
      DATA (ENRF(M), M=1,3)          /1.31,3.18,5.62/
      DATA (ENRS(G), G=1,4)          /2*1.59,7.32,6.42/
      DATA (FSYS(G), G=1,4)          /2*0.87,1.0,0.9/
      DATA (MAIDC(G), G=1,4)         /0.,4.5,0.,4.5/
      DATA ((MILKD(P,M), P=1,2),M=1,3)/18.,12.,23.,16.,28.,20./
      DATA (OEBC(C), C=1,4)          /-20.,20.,-20.,20./
      DATA (PERIOD(P), P=1,2)        /77.,107./
      DATA (R(P), P=1,2)             /1.0,0.95/
      DATA (RC(I), I=1,3)            /0.3,0.5,0.7/

      IF ((Z.EQ.1 .AND. G.LE.2) .OR. (Z.EQ.2)) THEN
         WRITE(50,'(1X,''P   ENRT DMIMAX  RM CONRDC RCON GIDC''
     *     ,'' MAIDC COIDC    C1    C2    C3    C4   ''
     *     ,''DVES   OEBIT  DSIDC SW'')')
      ENDIF

      IF (MILK .EQ. 5000.) THEN
         M=1
      ELSEIF (MILK .EQ. 6500.) THEN
         M=2
      ELSE
         M=3
      ENDIF

      MJMAIS    =6.23
      MJCON     =7.43
```

```
      MJDMGP(1) = MJDMG + 0.155
      MJDMGP(2) = MJDMG - 0.155

      DO 10 P=1,2

*----- Energy requirements of dairy cows (MJ cow-1 d-1)

         ENRP(P) = 3.04*MILKD(P,M) + 5.04*MILKD(P,M)**2./1000.
         ENRT(P)   = ENRM + ENRG + ENRP(P) + ENRS(G) + ENRC(P)
     *               + ENRF(M)

****** ration of the dairy cows
*----- dry matter intake from roughage

         MAXI(P)   = 1.1*(4.965 + 1.38*MJDMGP(P))*(0.6 + MILK/15000.)
     *                 *R(P)
         DMIMAX(P) = MAXI(P)*FSYS(G)
         RM(P)     = ((0.133*DMIMAX(P)/MAXI(P)*15. - 1.013)
     *               *(MJDMGP(P)/6.563)*(6.217/MJMAIS))/(0.6+MILK/15000.)
         IF (MAIDC(G) .EQ. 0.) RM(P) = 0.
         GIDC(P)   = MIN(DMIMAX(P) - RM(P)*MAIDC(G)
     *                 ,(ENRT(P)-MJMAIS*MAIDC(G))/MJDMGP(P))

*----- Concentrate input
         DO 100 I=1,3
             MJCONC(I) = MJCON - RC(I)*MJDMGP(P)
             CONIDC(I) = 0.0
100      CONTINUE

         CONRDC(P) = (ENRT(P) - MJDMGP(P)*GIDC(P) - MJMAIS*MAIDC(G))/
     *                MJCONC(1)

         IF (CONRDC(P) .LE. 0.0) THEN
             GO TO 200
         ELSEIF (CONRDC(P) .GT. 0.0 .AND. CONRDC(P) .LT. 3.5) THEN
             CONIDC(1) = CONRDC(P)
         ELSEIF (CONRDC(P) .GT. 3.5 .AND. CONRDC(P) .LT. 7.0) THEN
             CONIDC(1) = 3.5
             CONIDC(2) = (ENRT(P) - MJDMGP(P)*GIDC(P)-MJMAIS*(P)
     *                   - CONIDC(1)*MJCONC(1))/MJCONC(2)
         ELSE
             CONIDC(1) = 3.5
             CONIDC(2) = 3.5
             CONIDC(3) = (ENRT(P) - MJDMGP(P)*GIDC(P)-MJMAIS*MAIDC(G)
     *                   - CONIDC(1)*MJCONC(1) - CONIDC(2)*MJCONC(2))
     *                   /MJCONC(3)
         ENDIF

200      CONTINUE
```

```
          RCON(P)  = 0.0
          COIDC(P) = 0.0

          DO 300 I=1,3
              COIDC(P) = COIDC(P) + CONIDC(I)
              RCON(P)  = RCON(P) + CONIDC(I)*RC(I)
300       CONTINUE

          GIDC(P)  = GIDC(P) - RCON(P)
          DSIDC(P) = GIDC(P) + MAIDC(G) + COIDC(P)

          SW(P)    = (GIDC(P)*SWG + MAIDC(G)*SWM)/DSIDC(P)


****** protein requirement and supply (in g DVE, OEB dier-1 d-1)
*----- protein requirement

          DVERP(P) = MILKD(P,M) * 52.
          DVERT(P) = DVERM + DVERP(P) + DVERC(P)

*----- protein supply

          DVEIF(P) = DVEDMG*GIDC(P) + DVEMAI*MAIDC(G)
          OEBIF(P) = OEBDMG*GIDC(P) + OEBMAI*MAIDC(G)

          IF (COIDC(P) .NE. 0.0) THEN
              DVEIC(P) = DVERT(P) - DVEIF(P)
          ELSE
              DVEIC(P) = 0.0
          ENDIF

          DO 400 C=1,4
             CON(P,C) = 0.
             CI(C)    = DVEC(C)*COIDC(P)
400       CONTINUE

          IF (DVEIC(P) .LE. CI(1)) THEN
              CON(P,1) = COIDC(P)
          ELSE
              CON(P,1) = (DVEIC(P) - CI(2))/(DVEC(1)-DVEC(2))
              CON(P,2) = COIDC(P) - CON(P,1)
          ENDIF

          OEBI = OEBIF(P) + CON(P,1)*OEBC(1) + CON(P,2)*OEBC(2)
          IF (OEBI .LT. 0. .AND. CT .EQ. 0) THEN
              CON(P,1) = 0.
              CON(P,2) = COIDC(P)
              OEB2 = OEBIF(P) + CON(P,2)*OEBC(2)
              IF (OEB2 .GT. 0.) THEN
                  CON(P,1) = (-OEBIF(P) -COIDC(P)*OEBC(2))
```

```
     *                        /(OEBC(1) - OEBC(2))
                   CON(P,2) = COIDC(P) - CON(P,1)
               ENDIF
           ENDIF

           IF (OEBI .LT. 0. .AND. CT .EQ. 1) THEN
               CON(P,4) = CON(P,1)
               OEB4 = OEBIF(P) + CON(P,2)*OEBC(2) + CON(P,4)*OEBC(4)
               IF (OEB4 .GT. 0.) THEN
                   CON1     = CON(P,1)
                   CON(P,1) = (-OEBIF(P)-CON(P,2)*OEBC(2)-CON1*OEBC(4))
     *                        /(OEBC(1) - OEBC(4))
                   CON(P,4) = CON1 - CON(P,1)
               ELSE
                   CON(P,1) = 0.
               ENDIF
           ENDIF

           IF (OEBI .GT. 0. .AND. CT .EQ. 1) THEN
               CON(P,3) = CON(P,2)
               OEB3 = OEBIF(P) + CON(P,1)*OEBC(1) + CON(P,3)*OEBC(3)
               IF (OEB3 .LT. 0.) THEN
                   CON2     = CON(P,2)
                   CON(P,2) = (-OEBIF(P)-CON(P,1)*OEBC(1)-CON2*OEBC(3))
     *                        /(OEBC(2)-OEBC(3))
                   CON(P,3) = CON2 - CON(P,2)
               ELSE
                   CON(P,2) = 0.
               ENDIF
           ENDIF

           DVES(P)   = DVEIF(P) + CON(P,1)*DVEC(1) + CON(P,2)*DVEC(2)
     *               + CON(P,3)*DVEC(3) + CON(P,4)*DVEC(4) - DVERT(P)
           OEBIT(P) = OEBIF(P) + CON(P,1)*OEBC(1) + CON(P,2)*OEBC(2)
     *               + OEBC(3)*CON(P,3) + OEBC(4)*CON(P,4)

           CPI(P)  = 0.
           DCPI(P) = 0.

           DO 600 C=1,4
               CP(C)   = CN(C)*6.25*1000.
               CPI(P)  = CPI(P) + CP(C)*CON(P,C)
               DCPI(P) = DCPI(P) + FDCP(C)*CP(C)*CON(P,C)
 600       CONTINUE

           IF ((Z.EQ.1 .AND. G.LE.2) .OR. (Z.EQ.2)) THEN
               WRITE(50,'(1X,I1,F7.2,F6.1,F5.1,F6.2,F5.1,7F6.1,2F7.0,F6.1
     *             ,F5.2)')P,ENRT(P),DMIMAX(P),RM(P),CONRDC(P),RCON(P)
     *             ,GIDC(P),MAIDC(G),COIDC(P),CON(P,1),CON(P,2),CON(P,3)
     *             ,CON(P,4),DVES(P),OEBIT(P),DSIDC(P),SW(P)
```

```
            ENDIF

10      CONTINUE

        GIDCS  = PERIOD(1)*GIDC(1) + PERIOD(2)*GIDC(2)
        MAIDCS = PERIOD(1)*MAIDC(G) + PERIOD(2)*MAIDC(G)
        COIDCS = PERIOD(1)*COIDC(1) + PERIOD(2)*COIDC(2)

        IF (COIDCS .NE. 0.0) THEN
            CPCON = (CPI(1)*PERIOD(1) + CPI(2)*PERIOD(2))/COIDCS
            DCPC  = (DCPI(1)*PERIOD(1) + DCPI(2)*PERIOD(2))/COIDCS
            PDCC  = DCPC/CPCON
        ELSE
            CPCON = 0.
            DCPC  = 0.
            PDCC  = 0.
        ENDIF

        CNCON = CPCON/(6.25*1000.)

        IF ((Z.EQ.1 .AND. G.LE.2) .OR. (Z.EQ.2)) THEN
            WRITE(50,'(1X,''GIDCS  = '',F5.0,/,1X,''MAIDCS = '',F5.0,/
     *              ,1X,''COIDCS = '',F5.0,/,1X,''CNCON = '',F9.3,/
     *              ,1X,''FDCPO = '',F8.2,/)')
     *              GIDCS,MAIDCS,COIDCS,CNCON,PDCC
        ENDIF

        RETURN
        END
```

2.d Subroutine DISTRI

```
      SUBROUTINE DISTRI(D,AREAF,AREAU,F,FREST)
*-----------------------------------------------------------------------
*     calculation of distribution of faeces and urine over a field
*     using the Poisson distribution

      IMPLICIT REAL (A - Z)
      DIMENSION F(3,3),UR(3),FC(3)
      INTEGER     I,J,N

      FSUM = 0.0

      N     = 10*D
      MUU   = N*AREAU
      MUF   = N*AREAF

      DO 30 I=1,3
         DO 20 J=1,3
            UR(I)  = EXP(-MUU)*MUU**(I-1)/MAX(1.,(I-1))
            FC(J)  = EXP(-MUF)*MUF**(J-1)/MAX(1.,(J-1))
            F(I,J) = UR(I)*FC(J)
            FSUM   = FSUM+F(I,J)
20       CONTINUE
30    CONTINUE

      FREST  = 1.-FSUM
      IF (FREST.LT.0.001) FREST = 0.001

      DO 300 I=1,3
         DO 200 J=1,3
            WRITE(40,'(9(1X,F7.4,))')F(I,J)
200      CONTINUE
300   CONTINUE
      WRITE(40,'(1X,F7.4/)')FREST

      RETURN
      END
```

APPENDIX 3 RESULTS GRASSLAND MANAGEMENT MODEL

INPUTS

- N fertilizer rate : 250.
- cutting percentage : 150.
- milk production per cow : 6500.
- type of concentrate : 1

Run 1: zero grazing, no supply of maize silage

GRASSLAND (kg ha^{-1} yr^{-1})

	total	fresh	silage
dm gross	12877.	8377.	4500.
nett	11685.	7635.	4050.
N uptake	355.	238.	117.
N content		2.84	2.61
K uptake	435.	291.	144.
K content		3.48	3.20
desired K content		2.94	2.83
leaching	25.		
volatilization	1.		
utilization urine-N	.0		
utilization u+f K	.0		
N fertilizer	250.		
K fertilizer	366.		
P fertilizer	57.		
stocking rate		3.1590	

DAIRY COWS

	total	grass	maize	concentrates
milkproduction	10985.			
meatproduction	96.			
intake per day (kg)	14.9	13.1	.0	1.7
energy (MJ)	101.27	88.40	.00	12.87
nitrogen (kg)	.397	.373	.000	.024

N BALANCE GRASSLAND (kg ha^{-1} yr^{-1})

	total	uptake herbage	leaching NO3-N	volatil. NH3-N	balance loss	organic N soil	immobil. (inorg.N)
mineralization	153.	124.	13.				35.
deposition	45.	27.					
fertilizer	250.	205.	12.				33.
urine	0.	0.	0.	0.	0.		0.
faeces	0.			0.		0.	
grazing/harvesting losses	28.			1.		28.	
total		355.	25.	1.	0.	28.	68.

N BALANCE SOIL (kg ha^{-1} yr^{-1})

INORGANIC N	in		out
mineralisation	153.	uptake herbage	355.
deposition	45.	leaching	25.
fertilizer	250.	immobilisation	68.
urine	0.		

total	448.	total	448.

ORGANIC N	in		out
immobilisation	68.	mineralisation	153.
faeces	0.	surplus	-58.
grazing/harvesting losses	28.		
total	95.	total	95.

N BALANCE DAIRY COWS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates	type (%N)
intake	231.	217.	0.	14.	1.40
	total	urine	faeces	milk/meat	
excretion	231.	111.	60.	61.	
field	0.	0.	0.		
stable	170.	111.	60.		

INPUT/OUTPUT TABLE N

INPUT		OUTPUT	
deposition	45.	milk+meat	61.
mineralization	153.	leaching	25.
fertilizer	250.	volatilization	1.
maize+concentrates	14.	balance loss	0.
		slurry	175.
		silage	106.
		organic N pool	95.
total	462.	total	462.

K BALANCE GRASS (kg ha^{-1} yr^{-1})

	total	uptake	not accounted for
soil input	175.	175.	
deposition	9.	4.	5.
fertilizer	366.	256.	110.
urine + faeces	0.	0.	0.
grazing/harvesting losses	35.		35.
total		435.	149.

K BALANCE SOIL (kg ha^{-1} yr^{-1})

	in		out
mineralisation	175.	uptake herbage	435.
deposition	9.	mineralisation	175.
fertilizer	366.	surplus	-26.
urine+faeces	0.		
grazing/harvesting losses	35.		
total	585.	total	585.

INPUT/OUTPUT TABLE K

INPUT		OUTPUT	
deposition	9.	milk+meat	18.
soil input	175.	slurry	268.
fertilizer	366.	silage	130.

maize+concentrates	15.	surplus	149.
total	565.	total	565.

Run 2: zero grazing, supply maize silage

GRASSLAND (kg ha^{-1} yr^{-1})

	total	fresh	silage
dm gross	12877.	8377.	4500.
nett	11685.	7635.	4050.
N uptake	355.	238.	117.
N content		2.84	2.61
K uptake	435.	291.	144.
K content		3.48	3.20
desired K content		2.94	2.83
leaching	25.		
volatilization	1.		
utilization urine-N	.0		
utilization u+f K	.0		
N fertilizer	250.		
K fertilizer	366.		
P fertilizer	57.		
stocking rate		4.1349	

DAIRY COWS

	total	grass	maize	concentrates
milkproduction	14379.			
meatproduction	125.			
intake per day (kg)	15.3	10.0	4.5	.8
energy (MJ)	101.18	67.53	28.03	5.61
nitrogen (kg)	.360	.285	.065	.011

N BALANCE GRASSLAND (kg ha^{-1} yr^{-1})

	total	uptake herbage	leaching NO3-N	volatil. NH3-N	balance loss	organic N soil	immobil. (inorg.N)
mineralization	153.	124.	13.				35.
deposition	45.	27.					
fertilizer	250.	205.	12.				33.
urine	0.	0.	0.	0.	0.		0.
faeces	0.			0.		0.	
grazing/harvesting losses	28.			1.		28.	
total		355.	25.	1.	0.	28.	68.

N BALANCE SOIL (kg ha^{-1} yr^{-1})

INORGANIC N	in		out
mineralisation	153.	uptake herbage	355.
deposition	45.	leaching	25.
fertilizer	250.	immobilisation	68.
urine	0.		
total	448.	total	448.

ORGANIC N	in		out
immobilisation	68.	mineralisation	153.
faeces	0.	surplus	-58.

grazing/harvesting losses	28.		
total	95.	total	95.

N BALANCE DAIRY COWS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates	type (%N)
intake	274.	217.	49.	8.	1.41
	total	urine	faeces	milk/meat	
excretion	274.	115.	80.	79.	
field	0.	0.	0.		
stable	195.	115.	80.		

INPUT/OUTPUT TABLE N

INPUT		OUTPUT	
deposition	45.	milk+meat	79.
mineralization	153.	leaching	25.
fertilizer	250.	volatilization	1.
maize+concentrates	57.	balance loss	0.
		slurry	199.
		silage	106.
		organic N pool	95.
total	505.	total	505.

K BALANCE GRASS (kg ha^{-1} yr^{-1})

	total	uptake	not accounted for
soil input	175.	175.	
deposition	9.	4.	5.
fertilizer	366.	256.	110.
urine + faeces	0.	0.	0.
grazing/harvesting losses	35.		35.
total		435.	149.

K BALANCE SOIL (kg ha^{-1} yr^{-1})

	in		out
mineralisation	175.	uptake herbage	435.
deposition	9.	mineralisation	175.
fertilizer	366.	surplus	-26.
urine+faeces	0.		
grazing/harvesting losses	35.		
total	585.	total	585.

INPUT/OUTPUT TABLE K

INPUT		OUTPUT	
deposition	9.	milk+meat	23.
soil input	175.	slurry	315.
fertilizer	366.	silage	130.
maize+concentrates	67.	surplus	149.
total	617.	total	617.

Run 3: day and night grazing (no supply of maize silage)

GRASSLAND (kg ha^{-1} yr^{-1})

	total	fresh	silage
dm gross	12070.	7570.	4500.
nett	10106.	6056.	4050.
N uptake	379.	256.	123.
N content		3.38	2.73
K uptake	329.	222.	107.
K content		2.94	2.37
desired K content		3.20	2.89
leaching	43.		
volatilization	20.		
utilization urine-N	23.7		
utilization u+f K	34.4		
N fertilizer	250.		
K fertilizer	145.		
P fertilizer	24.		
stocking rate		2.1399	

DAIRY COWS

	total	grass	maize	concentrates
milkproduction	7441.			
meatproduction	65.			
intake per day (kg)	15.6	15.4	.0	.3
energy (MJ)	106.96	105.10	.00	1.86
nitrogen (kg)	.524	.520	.000	.004

N BALANCE GRASSLAND (kg ha^{-1} yr^{-1})

	total	uptake herbage	leaching NO3-N	volatil. NH3-N	balance loss	organic N soil	immobil. (inorg.N)
mineralization	153.	124.	13.				35.
deposition	45.	27.					
fertilizer	250.	205.	12.				33.
urine	99.	24.	18.	13.	27.		18.
faeces	38.			5.		33.	
grazing/harvesting losses	63.			2.		62.	
total		379.	43.	20.	27.	95.	85.

N BALANCE SOIL (kg ha^{-1} yr^{-1})

INORGANIC N	in		out
mineralisation	153.	uptake herbage	379.
deposition	45.	leaching	43.
fertilizer	250.	immobilisation	85.
urine	60.		
total	508.	total	508.

ORGANIC N	in		out
immobilisation	85.	mineralisation	153.
faeces	33.	surplus	27.
grazing/harvesting losses	62.		
total	180.	total	180.

N BALANCE DAIRY COWS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates	type (%N)
intake	206.	205.	0.	1.	1.40
	total	urine	faeces	milk/meat	

excretion	206.	119.	46.	41.
field	138.	99.	38.	
stable	28.	20.	8.	

INPUT/OUTPUT TABLE N

INPUT		OUTPUT	
deposition	45.	milk+meat	41.
mineralization	153.	leaching	43.
fertilizer	250.	volatilization	20.
maize+concentrates	1.	balance loss	27.
		slurry	28.
		silage	111.
		organic N pool	180.
total	449.	total	449.

K BALANCE GRASS (kg ha^{-1} yr^{-1})

	total	uptake	not accounted for
soil input	175.	175.	
deposition	9.	4.	5.
fertilizer	145.	102.	44.
urine + faeces	139.	48.	91.
grazing/harvesting losses	55.		55.
total		329.	195.

K BALANCE DAIRY COWS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates
intake	179.	178.	0.	1.
	total	urine	faeces	milk/meat
excretion	179.	151.	17.	12.
field	139.	125.	14.	
stable	28.	25.	3.	

K BALANCE SOIL (kg ha^{-1} yr^{-1})

	in		out
mineralisation	175.	uptake herbage	329.
deposition	9.	mineralisation	175.
fertilizer	145.	surplus	20.
urine+faeces	139.		
grazing/harvesting losses	55.		
total	524.	total	524.

INPUT/OUTPUT TABLE K

INPUT		OUTPUT	
deposition	9.	milk+meat	12.
soil input	175.	slurry	28.
fertilizer	145.	silage	96.
maize+concentrates	1.	surplus	195.
total	331.	total	331.

DETAILS OF URINE AND FAECES PATCHES

	part	dry matter	N urine	N faeces	N upt.	% N	NO3	K urine	K faeces	K upt.	% K	desired % K
U0F0	.7414	11900.	0.	0.	355.	3.21	25.	0.	0.	281.	2.54	3.12
U0F1	.0234	11900.	0.	1210.	355.	3.21	25.	0.	443.	454.	4.11	3.12
U0F2	.0004	11900.	0.	2420.	355.	3.21	25.	0.	885.	497.	4.50	3.12
U1F0	.1985	12608.	372.	0.	449.	3.82	82.	469.	0.	461.	3.93	3.41
U1F1	.0063	12608.	372.	1210.	449.	3.82	82.	469.	443.	523.	4.45	3.41
U1F2	.0001	12608.	372.	2420.	449.	3.82	82.	469.	885.	585.	4.98	3.41
U2F0	.0266	12838.	743.	0.	517.	4.33	227.	937.	0.	527.	4.41	3.65
U2F1	.0008	12838.	743.	1210.	517.	4.33	227.	937.	443.	588.	4.92	3.65
U2F2	.0000	12838.	743.	2420.	517.	4.33	227.	937.	885.	650.	5.44	3.65
REST	.0026	12947.	1142.	46.	560.	4.64	449.	1440.	17.	599.	4.95	3.80
av.	1.0000	12070.	99.	38.	379.	3.38	43.	125.	14.	329.	2.94	3.20

Run 4: day grazing only (supply of maize silage)

GRASSLAND (kg ha^{-1} yr^{-1})

	total	fresh	silage
dm gross	12007.	7507.	4500.
nett	10506.	6456.	4050.
N uptake	369.	248.	121.
N content		3.31	2.68
K uptake	366.	246.	119.
K content		3.28	2.65
desired K content		3.16	2.86
leaching	32.		
volatilization	12.		
utilization urine-N	25.4		
utilization u+f K	31.1		
N fertilizer	250.		
K fertilizer	220.		
P fertilizer	37.		
stocking rate		3.3532	

DAIRY COWS

	total	grass	maize	concentrates
milkproduction	11661.			
meatproduction	101.			
intake per day (kg)	15.9	10.5	4.5	.9
energy (MJ)	106.05	71.39	28.03	6.62
nitrogen (kg)	.424	.346	.065	.012

N BALANCE GRASSLAND (kg ha^{-1} yr^{-1})

	total	uptake herbage	leaching NO3-N	volatil. NH3-N	balance loss	organic N soil	immobil. (inorg.N)
mineralization	153.	124.	13.				35.
deposition	45.	27.					
fertilizer	250.	205.	12.				33.
urine	54.	14.	7.	7.	15.		11.
faeces	28.			4.		25.	
grazing/harvesting losses	47.			1.		45.	
total		369.	32.	12.	15.	70.	79.

N BALANCE SOIL (kg ha^{-1} yr^{-1})

INORGANIC N	in		out
mineralisation	153.	uptake herbage	369.
deposition	45.	leaching	32.
fertilizer	250.	immobilisation	79.
urine	32.		
total	480.	total	480.

ORGANIC N	in		out
immobilisation	79.	mineralisation	153.
faeces	25.	surplus	-4.
grazing/harvesting losses	45.		
total	149.	total	149.

N BALANCE DAIRY COWS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates	type (%N)
intake	261.	214.	40.	8.	1.40
	total	urine	faeces	milk/meat	
excretion	261.	129.	68.	64.	
field	82.	54.	28.		
stable	115.	75.	40.		

INPUT/OUTPUT TABLE N

INPUT		OUTPUT	
deposition	45.	milk+meat	64.
mineralization	153.	leaching	32.
fertilizer	250.	volatilization	12.
maize+concentrates	48.	balance loss	15.
		slurry	115.
		silage	109.
		organic N pool	149.
total	496.	total	496.

K BALANCE GRASS (kg ha^{-1} yr^{-1})

	total	uptake	not accounted for
soil input	175.	175.	
deposition	9.	4.	5.
fertilizer	220.	154.	66.
urine + faeces	103.	32.	71.
grazing/harvesting losses	46.		46.
total		366.	188.

K BALANCE DAIRY COWS (kg ha^{-1} yr^{-1})

	total	grass	maize	concentrates
intake	267.	212.	47.	8.
	total	urine	faeces	milk/meat
excretion	267.	223.	25.	19.
field	103.	93.	10.	
stable	145.	130.	14.	

K BALANCE SOIL (kg ha^{-1} yr^{-1})

	in		out
mineralisation	175.	uptake herbage	366.

deposition	9.	mineralisation	175.
fertilizer	220.	surplus	13.
urine+faeces	103.		
grazing/harvesting losses	46.		
total	554.	total	554.

INPUT/OUTPUT TABLE K

INPUT		OUTPUT	
deposition	9.	milk+meat	19.
soil input	175.	slurry	145.
fertilizer	220.	silage	108.
maize+concentrates	55.	surplus	188.
total	459.	total	459.

DETAILS OF URINE AND FAECES PATCHES

	part	dry matter	N urine	N faeces	N upt.	% N	NO3	K urine	K faeces	K upt.	% K	desired % K
U0F0	.7911	11900.	0.	0.	355.	3.21	25.	0.	0.	333.	3.02	3.12
U0F1	.0195	11900.	0.	1144.	355.	3.21	25.	0.	419.	478.	4.32	3.12
U0F2	.0002	11900.	0.	2287.	355.	3.21	25.	0.	838.	497.	4.50	3.12
U1F0	.1659	12443.	257.	0.	422.	3.64	55.	444.	0.	482.	4.16	3.32
U1F1	.0041	12443.	257.	1144.	422.	3.64	55.	444.	419.	545.	4.71	3.32
U1F2	.0001	12443.	257.	2287.	422.	3.64	55.	444.	838.	591.	5.10	3.32
U2F0	.0174	12739.	513.	0.	481.	4.05	131.	888.	0.	549.	4.63	3.52
U2F1	.0004	12739.	513.	1144.	481.	4.05	131.	888.	419.	612.	5.16	3.52
U2F2	.0000	12739.	513.	2287.	481.	4.05	131.	888.	838.	673.	5.67	3.52
REST	.0013	12864.	795.	41.	527.	4.40	267.	1374.	15.	622.	5.19	3.68
av.	1.0000	12007.	54.	28.	369.	3.31	32.	93.	10.	366.	3.28	3.16